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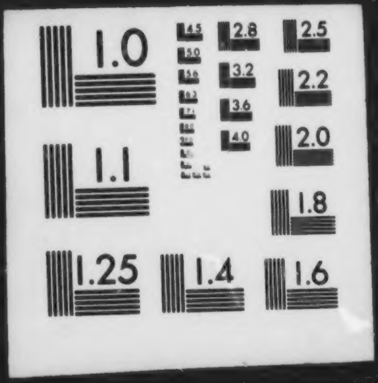
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PB-239 429

INFORMATION ON LEVELS OF ENVIRONMENTAL NOISE REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY

ENVIRONMENTAL PROTECTION AGENCY

MARCH 1974

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1921 Jefferson Davis Highway, Crystal Mall #2
Arlington, Virginia 20460

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MARCH 1974

PREPARED BY
THE U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF NOISE ABATEMENT AND CONTROL

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FOREWORD

The Congress included among the requirements of the Noise Control Act of 1972 a directive that the Administrator of the Environmental Protection Agency ". . .develop and publish criteria with respect to noise. . ." and then "publish information on the levels of environmental noise the attainment and maintenance of which in defined areas under various conditions are requisite to protect the public health and welfare with an adequate margin of safety."

Not all of the scientific work that is required for basing such levels of environmental noise on precise objective factors has been completed. Some investigations are currently underway, and the need for others has been identified. These involve both special studies on various aspects of effects of noise on humans and the accumulation of additional epidemiological data. In some cases, a considerable period of time must elapse before the results will be meaningful, due to the long-term nature of the investigations involved. Nonetheless, there is information available from which extrapolations are possible and about which reasoned judgments can be made.

Given the foregoing, EPA has sought to provide information on the levels of noise requisite to protect public health and welfare with an adequate margin of safety. The information presented is based on analyses, extrapolations and evaluations of the present state of scientific knowledge. This approach is not unusual or different from that used for other environmental stressors and pollutants. As pointed out in "Air Quality Criteria" – Staff Report, Subcommittee on Air and Water Pollution, Committee on Public Works, U.S. Senate, July, 1968,

> The protection of public health is required action based upon best evidence of causation available. This philosophy was appropriately expressed by Sir E. B. Hill, 1962, when he wrote: "All scientific work is incomplete – whether it be observational or experimental. All scientific work is liable to be upset or modified by advancing knowledge. That does not confer upon us freedom to lower the knowledge we already have, or to postpone the action that it appears to demand at a given time. The lessons of the past in general health and safety practices are easy to read. They are characterized by empirical decisions, by eternally persistent reappraisal of public health standards against available knowledge of causation, by consistently giving the public the benefit of the doubt, and by ever striving for improved environmental quality with the accompanying reduction in disease morbidity and mortality. The day of precise quantitative

> measurement of health and welfare effects has not yet arrived. Until such measurement is possible, action must be based upon limited knowledge, guided by the principal of the enhancement of the quality of human life. Such action is based on a philosophy of preventive medicine."

The foregoing represents the approach taken by EPA in the preparation of this present document on noise. As the fund of knowledge is expanded, improved and refined, revisions of this document will occur.

The incorporation of a margin of safety in the identification of non-hazardous levels is not new. In most cases, a statistical determination is made of the lowest level at which harmful effects could occur, and then an additional correction is applied as a margin of safety. In the case of noise, the margin of safety has been developed through the application of a conservative approach at each stage of the data analysis. The cumulation of these results thus provides for the adequate margin of safety.

It should be borne in mind that this document is published to present information required by the Noise Control Act, Section 5(a)(2), and that its contents do not constitute Agency regulations or standards. Its statistical generalizations should not be applied to a particular individual. Moreover, States and localities will approach this information according to their individual needs and situations.

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ABBREVIATIONS

AAOO	American Academy of Ophthalmology and Otolaryngology
AFR	Air Force Regulation
AI	Articulation Index
AMA	American Medical Association
ANSI	American National Standards Institute (formerly USASI)
ASHA	American Speech and Hearing Association
CHABA	Committee on Hearing and Bio-Acoustics
dBA	A-weighted decibel (decibels). Also written dB(A).
EPA	Environmental Protection Agency
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
NIOSH	National Institute for Occupational Safety and Health
NIPTS	Noise-Induced Permanent Threshold Shift
NITTS	Noise-Induced Temporary Threshold Shift
NPL	Noise Pollution Level (also National Physical Laboratory in England)
NR	Noise Rating
OSHA	Occupational Safety and Health Act
RMS	Root Mean Square
SIL	Speech Interference Level
SPL	Sound Pressure Level
TTS	Temporary Threshold Shift

TTS_2	TTS determined 2 minutes after cessation of exposure
$L_{(t)}$	Time-varying noise level
L_A	A-weighted sound level
L_b	"Background" or "residual" sound level, A-weighted
L_d	Daytime equivalent A-weighted sound level between the hours of 0700 and 2200
L_e	Sound exposure level—the level of sound accumulated during a given event.
L_{dn}	Day-night average sound level—the 24 hour A-weighted equivalent sound level, with a 10 decibel penalty applied to nighttime levels
L_{eq}	Equivalent A-weighted sound level over a given time interval
$L_{eq(8)}$	Equivalent A-weighted sound level over eight hours
$L_{eq(24)}$	Equivalent A-weighted sound level over 24 hours
L_h	Hourly equivalent A-weighted sound level
L_n	Nighttime equivalent A-weighted sound level between the hours of 2200 and 0700
L_{max}	Maximum A-weighted sound level for a given time interval or event
L_x	X-percent sound level, the A-weighted sound level equaled or exceeded x% of time
ΔL	Difference in decibels between two different A-weighted sound levels

Section 1

INTRODUCTION

The Noise Control Act of 1972 established by statutory mandate a national policy "to promote an environment for all Americans free from noise that jeopardizes their public health and welfare". The Act provides for a division of powers between the Federal and state and local governments, in which the primary Federal responsibility is for noise source emission control, with the states and other political subdivisions retaining rights and authorities for primary responsibility to control the use of noise sources and the levels of noise to be permitted in their environment.

In order to provide adequately for the Federal emission control requirement and to insure Federal assistance and guidance to the state and localities, the Congress has established two separate but related requirements with regard to scientific information about health and welfare effects of noise. First, the Environmental Protection Agency was called upon to publish descriptive data on the effect of noise which might be expected from various levels and exposure situations. Such "criteria" statements are typical of other environmental regulatory schemes. Secondly, the Agency is required to publish "information" as to the levels of noise "requisite to protect the public health and welfare with an adequate margin of safety".

SUMMARY

The first requirement was completed in July, 1973, when the document "Public Health and Welfare Criteria for Noise" was published. The present document represents the second step. Much of the scientific material on which this document is based was drawn from the earlier "criteria document", while additional material was gathered from scientific publications and other sources, both from the U.S. and abroad. In addition, two review meetings were held which were attended by representatives of the Federal agencies as well as distinguished members of the professional community and representatives from industrial and environmental associations. The reviewers' suggestions, both oral and written, have received thoughtful attention, and their comments incorporated to the extent feasible and appropriate.

After a great deal of analysis and deliberation, levels were identified to protect public health and welfare for a large number of situations. These levels are subject to the definitions and qualifications contained in the Foreword. They are summarized in Table 1 according to the public health and welfare effect to be protected against, the requisite sound level, and the areas which are appropriate for such protection.

In order to identify these levels, a number of considerations and hypotheses were necessary, which are listed below with reference to the appropriate appendices where they are discussed in detail.

1. In order to describe the effects of environmental noise in a simple, uniform and appropriate way, the best descriptors are the long-term equivalent A-weighted sound level (L_{eq}) and a variation with a nighttime weighting, the day-night sound level (L_{dn}) (see Appendix A).

2. To protect against hearing impairment (see Appendix C):

   a. The human ear, when damaged by noise, is typically affected first at the audiometric frequency of 4000 Hz.

   b. Changes in hearing level of less than 5 dB are generally not considered noticeable or significant.

   c. One cannot be damaged by sounds considered normally audible, which one cannot hear.

   d. Protecting the population up to a critical percentile (ranked according to decreasing ability to hear) will also protect those above that percentile, (in view of consideration 2c above) thereby protecting virtually the entire population.

3. To correct for intermittency and duration in identifying the appropriate level to protect against hearing loss (also, see Appendix C):

   a. The Equal Energy Hypothesis

   b. The TTS Hypothesis

4. To identify levels requisite to protect against activity interference (see Appendix D):

   a. Annoyance due to noise, as measured by community surveys, is the consequence of activity interference.

   b. Of the various kinds of activity interference, speech interference is the one that is most readily quantifiable.

Table 1

SUMMARY OF NOISE LEVELS IDENTIFIED AS REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY

(see Table 4 for detailed description)

EFFECT	LEVEL	AREA
Hearing Loss	$L_{eq(24)} \leq 70$ dB	All areas
Outdoor activity interference and annoyance	$L_{dn} \leq 55$ dB	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq(24)} \leq 55$ dB	Outdoor areas where people spend limited amounts of time, such as school yards, playgrounds, etc.
Indoor activity interference and annoyance	$L_{dn} \leq 45$ dB	Indoor residential areas
	$L_{eq(24)} \leq 45$ dB	Other indoor areas with human activities such as schools, etc.

Explanation of Table 1:

1. Detailed discussions of the terms L_{dn} and L_{eq} appear later in the document. Briefly, $L_{eq(24)}$ represents the sound energy averaged over a 24-hour period while L_{dn} represents the L_{eq} with a 10 dB nighttime weighting.

2. The hearing loss level identified here represents annual averages of the daily level over a period of forty years. (These are energy averages, not to be confused with arithmetic averages.)

3. Relationship of an $L_{eq(24)}$ of 70 dB to higher exposure levels.

EPA has determined that for purposes of hearing conservation alone, a level which is protective of that segment of the population at or below the 96th percentile will protect virtually the entire population. This level has been calculated to be an L_{eq} of 70 dB over a 24-hour day.

Given this quantity, it is possible to calculate levels which, when averaged over given durations shorter than 24 hours, result in equivalent amounts of energy. For example, the energy contained in an 8-hour exposure to 75 dB is equivalent to the energy contained in a 24-hour exposure to 70 dB. For practical purposes, the former exposure is only equivalent to the latter when the average level of the remaining 16 hours per day is negligible (i.e., no more than about 60 dB* for this case).

Since 8 hours is the typical daily work period, an $L_{eq(8)}$ of 75 is considered an appropriate level for this particular duration. In addition, the 24-hour exposure level was derived from data on 8-hour daily exposures over a 40-year working life. In planning community noise abatement activities, local governments should bear in mind the special needs of those residents who experience levels higher than $L_{eq(8)}$ at 70 on their jobs.

These levels are not to be construed as standards as they do not take into account cost or feasibility. Nor should they be thought of as discrete numbers, since they are described in terms of energy equivalents. As specified in this document, it is EPA's judgment that the maintenance of levels of environmental noise at or below those specified above are requisite to protect the public from adverse health and welfare effects. Thus, as an individual moves from a relatively quiet home, through the transportation cycle, to a somewhat noisier occupational situation, and then back home again, his hearing will not be impaired if the daily equivalent of sound energy in his environment is no more than 70 decibels. Likewise, undue
1 interference with activity and annoyance will not occur if outdoor levels are maintained at an energy equivalent of 55 dB and indoor levels at 45 dB. However, it is always assumed throughout that environmental levels will fluctuate, even though the identified energy equivalent is not exceeded. Likewise, human exposure to noise will vary during the day, even though the daily "dose" may correspond well to the identified levels.

Before progressing further, it would be helpful to differentiate between the terms "levels", "exposure" and "dose". As used in this document, the word "level" refers to the magnitude of sound in its physical dimension, whether or not there are humans present to hear it. "Exposure" is used to mean those sound levels which are transmitted to the human ear, and "dose"is the summed exposure over a period of time.

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* This is not to imply that 60 dB is a negligible exposure level in terms of health and welfare considerations, but rather that levels of 60 dB make a negligible contribution to the energy average of L_{eq} = 70 dB when an 8-hour exposure of 75 dB is included.

LEGISLATIVE HISTORY

Pursuant to Section 5(a)(1), EPA developed and published on July 27, 1973, criteria reflecting:

> . . .the scientific knowledge most useful in indicating the kind and extent of all identifiable effects on the public health or welfare which may be expected from differing quantities and qualities of noise.

Under Section 5(a)(1), EPA was required to provide scientific data that, in its judgement, was most appropriate to characterize noise effects.

The present "levels information" document is required by Section 5(a)(2), which calls for EPA to publish,

> . . .information on the levels of environmental noise the attainment and maintenance of which in defined areas under various conditions are requisite to protect the public health and welfare with an adequate margin of safety.

The present document, and its approach to identifying noise levels based on cumulative noise exposure is in response to the expressed intent of the Congress that the Agency develop such a methodology. The EPA Report to the President and Congress, under Title IV, PL 91-604, contained considerable material on the various schemes for measuring and evaluating community noise response, and it contained a recommendation that the Federal government should make an assessment of the large number of varying systems, with a goal of "standardization, simplification, and interchangeability of data".

The need for such action was the subject of considerable Congressional interest in the hearings on the various noise control bills, which finally resulted in enactment of the Noise Control Act of 1972. The concept underlying this present document can be better appreciated from the following pertinent elements of the legislative history of the Act.

In the course of the hearings before the Subcommittee on Public Health and Environment of the Committee on Interstate and Foreign Commerce, House of Representatives ("Noise Control" HR Serial 92-30), the subject of the relation of physical noise measurements to human response was given considerable attention. The Committee, in reporting the bill (House of Representatives Report No. 92-842, Noise Control Act of 1972), stated the following on this matter:

> The Committee notes that most of the information relating to noise exposures was concerned with specific sources, rather than typical

> cumulative exposures to which urban and suburban dwellers are commonly exposed. There is a need for much greater effort to determine the magnitude and extent of such exposures and the Committee expects the EPA to promote studies on this subject and consider development of methods of uniform measurement of the impact of noise on communities.

The Committee went on in the Report to assign responsibility to the Administrator to coordinate all Federal noise programs, with a specific expression of concern over the "different systems of noise measurement" in use by the various Agencies. The following is especially important with respect to the purposes of this document:

> The Committee gave some consideration to the establishment of a Federal ambient noise standard, but rejected the concept. Establishment of a Federal ambient standard would in effect put the Federal Government in the position of establishing land use zoning requirements on the basis of noise. . . . It is the Committee's view that this function is one more properly of the states and their political subdivisions, and that the Federal Government should provide guidance and leadership in undertaking that effort.

The need for EPA action on this subject under the legislative authority of the Act was presented in Agency testimony before the Subcommittee on Air and Water Pollution, Committee on Public Works, U. S. Senate. The following portion is important (Noise Pollution Serial 92-H35 U. S. Senate):

> A variety of specialized schemes have been evolved over the past years to quantify the relationship between these various conditions and their effects on humans. . . . Suffice it to say that no simplistic single number system can adequately provide for a uniform acceptable national ambient noise level value. This, however, does not preclude the undertaking of a noise abatement strategy involving the proper use of the available scientific data on the part of the Federal Government in conjunction with the state and local governments. . . . The complex nature of the considerations we have outlined above in our judgment require that the Federal Government undertake to provide the necessary information upon which to base judgments. . . .

Taking both the specific language of the Act, cited above, and the legislative history discussed in the foregoing, EPA interprets Section 5(a)(2) as directing the Agency to identify levels based only on health and welfare effects and *not* on technical feasibility or economic costs.

Throughout this report, the words "identified level" are used to express the result of the inquiry mandated by Section 5(a)(2). The words "goals", "standards", or "recommended levels" are not used since they are not appropriate. Neither Congress nor the Environmental Protection Agency has reached the conclusion that these identified levels should be adopted by states and localities. This is a decision which the Noise Control Act clearly leaves to the states and localities themselves.

Certain of the statutory phrases in Section 5(a)(2) need further definition and discussion in order to make clear the purpose of this document. Congress required that EPA "publish information on environmental noise" levels. This mandate is basically one of "description". Such description is to be made in the specific context of "defined areas" and "under various conditions". The phrase "in defined areas under various conditions" is used in both a geographical and an activity sense, for example, indoors in a school classroom or outdoors adjacent to an urban freeway. It also requires consideration not only of the human activity involved, but also of the nature of the noise impact.

The next and last statutory phrase in Section 5(a)(2) is most important. It is that the noise levels are to be discussed on the basis of what is requisite to protect "the public health and welfare with an adequate margin of safety". The use of the words "public health" requires a statistical approach to determine the order of magnitude of the population affected by a given level of noise. The concept of a margin of safety implies that every sector of the population which would reasonably be exposed to adverse noise levels should be included by the specifically described levels.

The phrase "health and welfare" as used herein is defined as "complete physical, mental and social well-being and not merely the absence of disease and infirmity". This definition would take into account sub-clinical and subjective responses (e.g., annoyance or other adverse psychological reactions) of the individual and the public. As will be discussed below, the available data demonstrate that the most serious clinical health and welfare effect caused by noise is interference with the ability to hear. Thus, as used in this document, the phrase "health and welfare" will necessarily apply to those levels of noise that have been shown to interfere with the ability to hear.

The phrase "health and welfare" also includes personal comfort and well-being and the absence of mental anguish and annoyance. In fact, a considerable portion of the data available on the "health and welfare" effects of noise is expressed in terms of annoyance. However, "annoyance" is a description of the human reaction to what is described as noise "interference"; and though annoyance appears to be statistically quantifiable, it is a subjective reaction to interference with some desired human activity. From a legal standpoint, annoyance *per se* is not a legal concept. Annoyance expresses the human response or results, *not* its cause. For this reason, the common law has never recognized annoyance as being a compensable injury, in the absence of interference with a personal or property right. Of the many community surveys on noise which have been conducted, speech interference emerges as the most tangible component of annoyance, whereas sleep and other kinds of activity interference are important, but less well-defined contributors. Thus, although it is important to understand the importance of annoyance as a concept, it is the actual interference with activity on which the levels identified in this document are based.

There was a great deal of concern during the preparation of this document that the levels identified would be mistakenly interpreted as Federal noise standards. The information contained in this document should not be so interpreted. The general purpose of this document is rather to discuss environmental noise levels requisite for the protection of public health and welfare without consideration of those elements necessary to an actual rule-making. Those elements not considered in this document include economic and technological feasibility and attitudes about the desirability of undertaking an activity which produces interference effects. Instead, the levels identified here will provide State and local governments as well as the Federal Government and the private sector with an informational point of departure for the purpose of decision-making.

An even more important, but related point must be kept in mind when this document is read. The data on which the informational levels in this document are based are not "short run" or single event noises. Rather, they represent energy equivalent noise levels over a long period. For example, the exposure period which results in no more than 5 dB hearing loss at the identified level in Tables 1 and 4 is a period of forty years.

The definition of "environmental noise" is provided in Section 3(11) of the Noise Control Act of 1972. "The term 'environmental noise' means the intensity, duration, and the character of sounds from all sources." As discussed earlier, it is the intent of Congress that a simple, uniform measure of noise be developed. Not all information contained in the noise environment can be easily considered and analyzed. Instead, for practical purposes, it needs to be condensed to result in one indicator of the environmental quantity and quality of noise which correlates with the overall long-term effects of noise on public health and welfare.

Many noise rating and evaluation procedures are available in the literature,[2,3] in voluntary national and international standards, and in commonly used engineering practices (see Appendix A). These methods and practices are well established, and it is not the purpose of this document to list them, elaborate on them, or imply a restriction of their use. Instead, the purpose is to discuss levels of environmental noise using a measure which correlates with other measures and can be applied to most situations. Based on the concept of the cumulative human exposure to environmental noise associated with the various life styles of the population, maximum long-term exposures for individuals and the corresponding environmental noise levels at various places can be identified. It is important to keep in mind that the selected indicator of environment noise does not correlate uniquely with any specific effect on human health or performance. Admittedly, there are uncertainties with respect to effects in individual cases and situations. Such effects cannot be completely accounted for; thus, the necessity to employ a statistical approach.

Section 2 of the report addresses the details of characterizing and measuring human exposure to environmental noise. The equivalent sound level (L_{eq}) and a variation weighted for nighttime exposure (L_{dn}) has been selected as the uniform descriptor. The relationship of L_{eq} and L_{dn} to other measures in use is analyzed in Appendix A. Section 2 and Appendix B further detail the various human exposure patterns and give simplified examples of individual exposure patterns. The problem of separating occupational exposure from the balance of environmental exposure and the statutory responsibility for controlling occupational exposure is analyzed in Appendix F.

In Section 3, cause and effect relationships are summarized and presented as the basis and justification for the environmental noise levels identified in Section 4. Specifically, Section 3 develops conclusions with regard to levels at which hearing impairment and activity interference take place. These are discussed in terms of situational variation and the respective appropriateness of L_{eq} and L_{dn}. The factors providing for an adequate margin of safety and special types of noises are discussed. This section makes reference to material in Appendices C (on hearing loss), D (annoyance and activity interference) and G (special noises), which in turn rely upon material presented in EPA's document, Public Health and Welfare Criteria for Noise,[2] to which the reader is referred for more detailed information.

Section 4 discusses the levels of environmental noise requisite to protect public health and welfare for various indoor and outdoor areas in the public and private domain in terms of L_{eq} and L_{dn}. The summary table is supplemented by short explanations.

It is obvious that the practical application of the levels to the various purposes outlined earlier requires considerations of factors not discussed here. Although some guidance in this respect is included in Section 4, not all problems can be anticipated and some of these questions can only be resolved as the information contained in this report is considered and applied. Such practical experiences combined with results of further research will guide EPA in revising and updating the levels identified. In this regard, it should be recognized that certain of the levels herein might well be subject to revision when additional data are developed.

Section 2

ENVIRONMENTAL NOISE EXPOSURE

A complete physical description of a sound must describe its magnitude, its frequency spectrum, and the variations of both of these parameters in time. However, one must choose between the ultimate refinement in measurement techniques and a practical approach that is no more complicated than necessary to predict the impact of noise on people. The Environmental Protection Agency's choice for the measurement of environmental noise is based on the following considerations:

1. The measure should be applicable to the evaluation of pervasive long-term noise in various defined areas and under various conditions over long periods of time.

2. The measure should correlate well with known effects of the noise environment on the individual and the public.

3. The measure should be simple, practical and accurate. In principle, it should be useful for planning as well as for enforcement or monitoring purposes.

4. The required measurement equipment, with standardized characteristics, should be commercially available.

5. The measure should be closely related to existing methods currently in use.

6. The single measure of noise at a given location should be predictable, within an acceptable tolerance, from knowledge of the physical events producing the noise.

7. The measure should lend itself to small, simple monitors which can be left unattended in public areas for long periods of time.

These considerations, when coupled with the physical attributes of sound that influence human response, lead EPA to the conclusion that the magnitude of sound is of most importance insofar as cumulative noise effects are concerned. Long-term average sound level, henceforth referred to as equivalent sound level (L_{eq}), is considered the best measure for the magnitude of environmental noise to fulfill the above seven requirements. Several versions of equivalent sound level will be used for identifying levels of sound in specific places requisite to protect public health and welfare. These versions differ from each other primarily in the time intervals over which the sound levels are of interest, and the correction factor employed.

Equivalent A-weighted sound level is the constant sound level that, in a given situation and time period, conveys the same sound energy as the actual time-varying A-weighted sound.* The basic unit of equivalent sound levels is the decibel (see Appendix A), and the symbol for equivalent sound level is L_{eq}. Two sounds, one of which contains twice as much energy but lasts only half as long as the other, would be characterized by the same equivalent sound level; so would a sound with four times the energy lasting one fourth as long. The relation is often called the equal-energy rule. A more complete discussion of the computation of equivalent sound level, its evolution and application to environmental noise problems, and its relationship to other measures used to characterize environmental noise is provided in Appendix A.

The following caution is called to the attention of those who may prescribe levels: It should be noted that the use of equivalent sound level in measuring environmental noise will not directly exclude the existence of very high noise levels of short duration. For example, an equivalent sound level of 60 dB over a twenty-four hour day would permit sound levels of 110 dB but would limit them to less than one second duration in the twenty-four hour period. Comparable relationships between maximum sound levels and their permissible durations can easily be obtained for any combination, relative to any equivalent sound level (see the charts provided in Appendix A).

Three basic situations are used in this document for the purpose of identifying levels of environmental noise:

1. Defined areas and conditions in which people are exposed to environmental noise for periods of time which are usually less than twenty-four hours, such as school classrooms, or occupational settings.

2. Defined areas and conditions in which people are exposed to environmental noise for extended periods of time, such as dwellings.

3. Total noise exposure of an individual, irrespective of area or condition.

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*See Glossary for a detailed definition of terms. Note that when the term "sound level" is used throughout this document, it always implies the use of the A-weighting for frequency.

Three versions of equivalent sound level are used in this document in order to accommodate the various modes of noise exposure that occur in these situations. They are distinguished by the periods of time over which they are averaged and the way in which the averaging is done.

1. L_{eq} for an 8-hour period ($L_{eq(8)}$): This is the equivalent A-weighted sound level (in decibels relative to 20 micropascals) computed over any continuous time period of eight hours identified with the typical occupational exposure. As will be shown in later sections of this document, $L_{eq(8)}$ serves as a basis for identifying environmental noise which causes damage to hearing.

2. L_{eq} for 24-hour weighted for nighttime exposure (L_{dn}): This formula of equivalent level is used here to relate noise in residential environments to chronic annoyance by speech interference and in some part by sleep and activity interference. For these situations, where people are affected by environmental noise for extended periods of time, the natural choice of duration is the 24-hour day. Most noise environments are characterized by repetitive behavior from day to day, with some variation imposed by differences between weekday and weekend activity, as well as some seasonal variation. To account for these variations, it has been found useful to measure environmental noise in terms of the long-term yearly average of the daily levels.

In determining the daily measure of environmental noise, it is important to account for the difference in response of people in residential areas to noises that occur during sleeping hours as compared to waking hours. During nighttime, exterior background noises generally drop in level from daytime values. Further, the activity of most households decreases at night, lowering the internally generated noise levels. Thus, noise events become more intrusive at night, since the increase in noise levels of the event over background noise is greater than it is during the daytime.

Methods for accounting for these differences between daytime and nighttime exposures have been developed in a number of different noise assessment methods employed around the world, (see Appendix A). In general, the method used is to characterize nighttime noise as more severe than corresponding daytime events; that is, to apply a weighting factor to noise that increases the numbers commensurate with their severity. Two approaches to identifying time periods have been employed: one divides the 24-hour day into two periods, the waking and sleeping hours, while the other divides the 24 hours into three periods—day, evening, and night. The weighting applied to the non-daytime periods differs slightly among the different countries, but most of them weight nighttime activities by about 10 dB. The evening weighting, if used, is 5 dB.

An examination of the numerical values obtained by using two periods versus three periods per day shows that for any reasonable distribution of environmental noise levels, the two-period day and the three-period day are essentially identical; i.e., the 24-hour equivalent sound levels are equal within a few tenths of a decibel. Therefore, the simpler two-period day is used in this document, with daytime extending from 7 a.m. to 10 p.m. and nighttime extending from 10 p.m. to 7 a.m. The symbol for the 15-hour daytime equivalent sound level is L_d, the symbol for the 9-hour nighttime equivalent sound level is L_n, and the day-night weighted measure is symbolized as L_{dn}.

The L_{dn} is defined as the A-weighted average sound level in decibels (re 20 micropascals) during a 24-hour period with a 10 dB weighting applied to nighttime sound levels. Examples of the outdoor present day (1973) day-night noise level at typical locations are given in Figure 1.

3. L_{eq} for the 24-hour average sound level to which an individual is exposed (L_{eq} (24)): This situation is related to the cumulative noise exposure experienced by an individual irrespective of where, or under what situation, this exposure is received. The long-term health and welfare effects of noise on an individual are related to the cumulative noise exposure he receives over a lifetime.

Relatively little is known concerning the total effect of such lifetime exposures, but dose-effect relations have been studied for two selected situations:

a. The average long-term exposure to noise primarily in residential areas leading to annoyance reactions and complaints.

b. The long-term effects of occupational noise on hearing, with the daily exposure dose based on an eight-hour work day.

An ideal approach to identifying environmental noise levels in terms of their effect on public health and welfare would be to start by identifying the maximum noise not to be exceeded by individuals. However, the noise dose that an individual receives is a function of lifestyle. For example, exposure patterns of office workers, factory workers, housewives, and school children are quite different. Within each group the exposures will vary widely as a function of the working, recreational, and sleeping patterns of the individual. Thus, two individuals working in the same office will probably accumulate different total noise doses if they use different modes of transportation, live in different areas, and have different TV habits. Examples of these variations in noise dose for several typical life styles are provided in Appendix B. However, detailed statistical information on the distribution of actual noise doses and the relationship of these doses to long-term health and welfare effects is still missing. Therefore, a realistic approach to this problem is to identify appropriate noise levels for

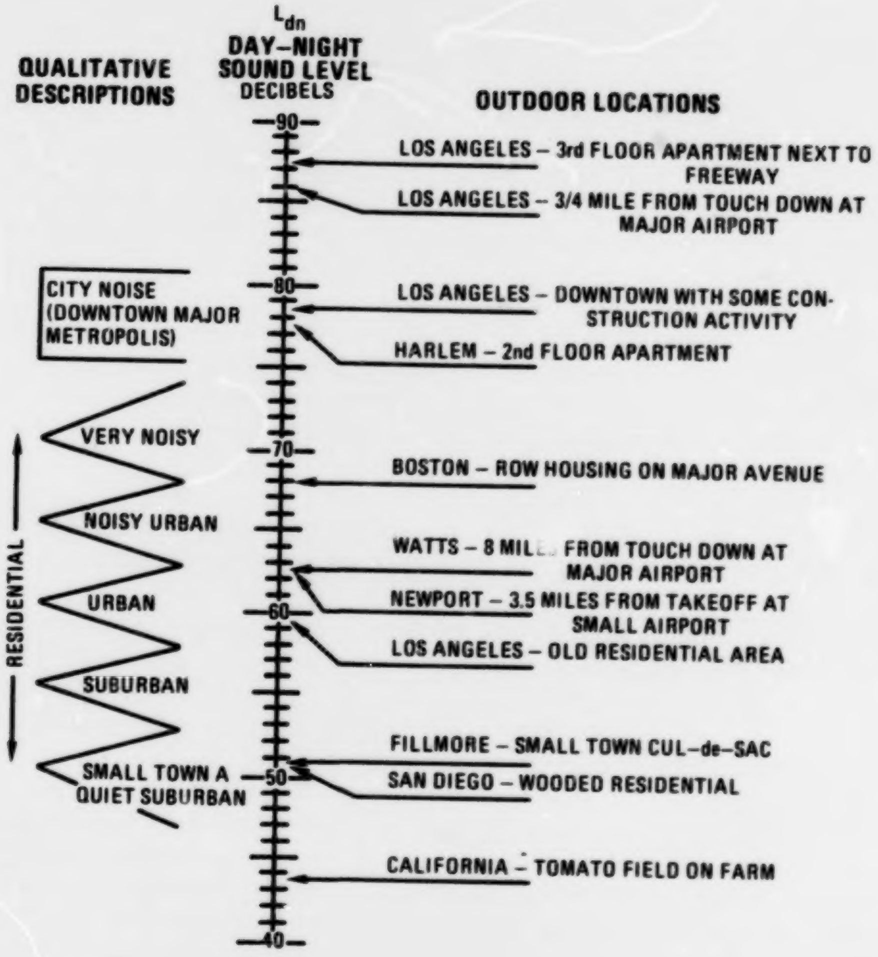
QUALITATIVE DESCRIPTIONS
L_dn
DAY-NIGHT SOUND LEVEL DECIBELS
OUTDOOR LOCATIONS
90
80
70
60
50
40
CITY NOISE (DOWNTOWN MAJOR METROPOLIS)
RESIDENTIAL
VERY NOISY
NOISY URBAN
URBAN
SUBURBAN
SMALL TOWN A QUIET SUBURBAN
LOS ANGELES – 3rd FLOOR APARTMENT NEXT TO FREEWAY
LOS ANGELES – 3/4 MILE FROM TOUCH DOWN AT MAJOR AIRPORT
LOS ANGELES – DOWNTOWN WITH SOME CONSTRUCTION ACTIVITY
HARLEM – 2nd FLOOR APARTMENT
BOSTON – ROW HOUSING ON MAJOR AVENUE
WATTS – 8 MILES FROM TOUCH DOWN AT MAJOR AIRPORT
NEWPORT – 3.5 MILES FROM TAKEOFF AT SMALL AIRPORT
LOS ANGELES – OLD RESIDENTIAL AREA
FILLMORE – SMALL TOWN CUL-de-SAC
SAN DIEGO – WOODED RESIDENTIAL
CALIFORNIA – TOMATO FIELD ON FARM

Figure 1. Outdoor Day-Night Sound Level in dB (re 20 micropascals) at Various Locations[4]

places occupied by people as a function of the activity in which they are engaged, including a gross estimate of typical average exposure times.

From a practical viewpoint, it is necessary to utilize the wealth of data relating to occupational noise exposure, some of it, albeit, subject to interpretation, in order to arrive at extrapolations upon which the identification of safe levels for daily (24-hour) exposures can be based.

In the following sections of this report, the various modes of exposure to noise and the human responses elicited will be discussed, leading to the identification of appropriate noise exposure levels. In order to assist the reader in associating these levels with numerical values of noise for familiar situations, typical noise levels encountered at various locations are listed in Table 2. For further assistance, Figure 2 provides an estimate of outdoor noise levels for different residential areas.

Table 2

EQUIVALENT SOUND LEVELS IN DECIBELS NORMALLY OCCURRING INSIDE VARIOUS PLACES[6]

SPACE	L_{eq}(+)
Small Store (1-5 clerks)	60
Large Store (more than 5 clerks)	65
Small Office (1-2 desks)	58
Medium Office (3-10 desks)	63
Large Office (more than 10 desks)	67
Miscellaneous Business	63
Residences	
Typical movement of people–no TV or radio	40-45
Speech at 10 feet, normal voice	55
TV listening at 10 feet, no other activity	55-60
Stereo music	50-70

(+) These measurements were taken over durations typical of the operation of these facilities.

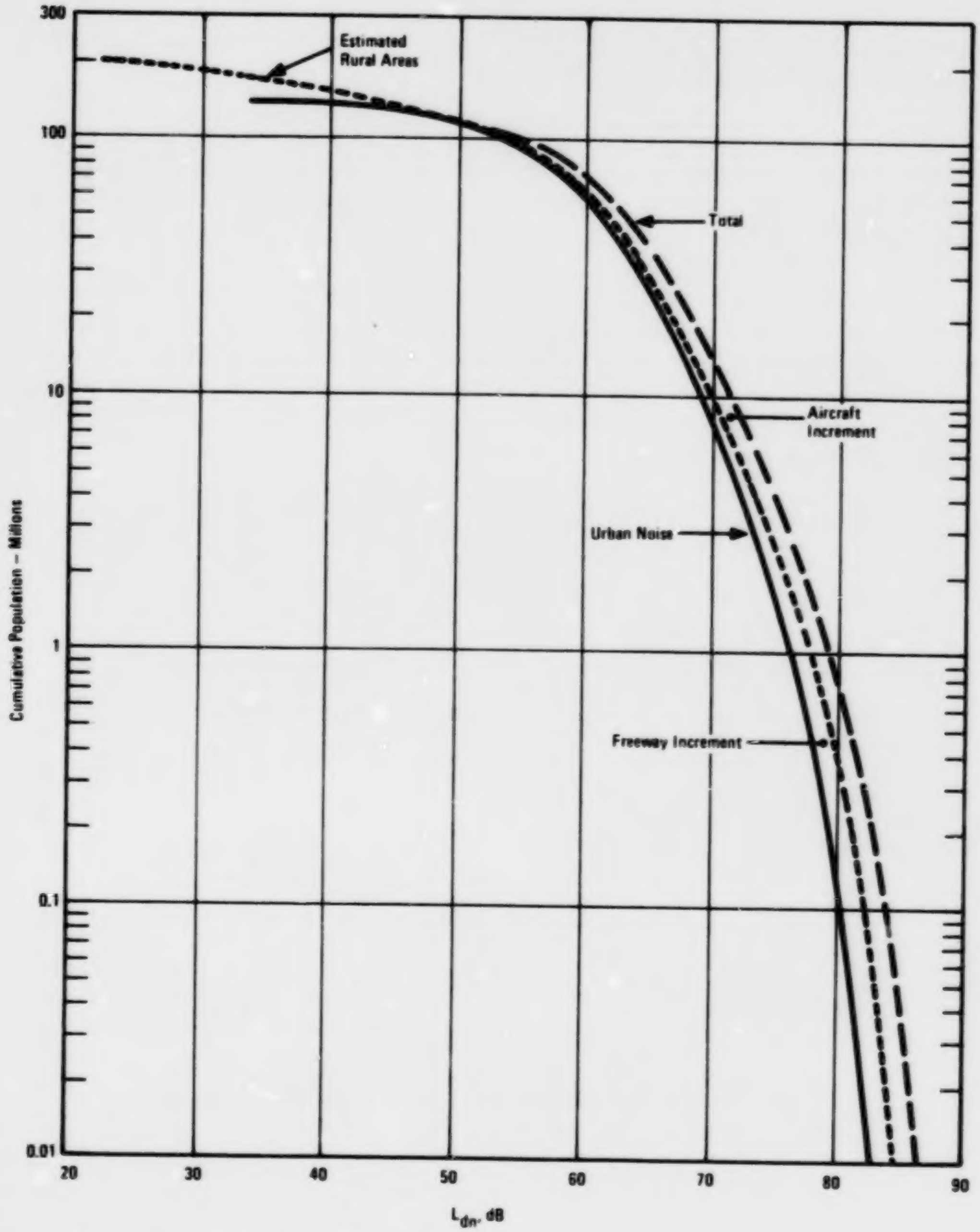

Figure 2. Residential Noise Environment of the National Population As a Function of Exterior Day-Night Average Sound Level[B-5]

Section 3

RATIONALE FOR IDENTIFICATION OF LEVELS OF ENVIRONMENTAL NOISE REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE

BASIS FOR IDENTIFYING LEVELS

For the identification of levels to protect against the direct, disease-producing effects of noise, protection against hearing loss is the guiding consideration. At this time, there is insufficient scientific evidence that non-auditory diseases are caused by noise levels lower than those that cause noise-induced hearing loss. In the event that future research renders this conclusion invalid, this document will be revised accordingly (see Appendix E).

In addition to direct disease-producing health effects, interference by noise with various human activities, such as speech-perception, sleep, and thought can lead to annoyance and indirect effects on well-being. All of these direct and indirect effects are considered here as effects on public health and welfare. It is important to note, however, the distinction between voluntary and involuntary exposures. Exposures to high levels of environmental noise are often produced or sought by the individual. For example, voluntary exposures to loud music are common. Consequently, the concept of total individual noise dose with regard to annoyance, must be applied only to involuntary exposure, although, of course, this argument does not apply to the effects of noise on hearing.

A further consideration is the physical setting in which the exposure takes place. Although there are no data to justify the assumption, it is judged here that, whereas a small amount of speech interference in most outdoor places is not detrimental to public health and welfare, the same is not true for most indoor environments. Based on this reasoning, adequate protection of the public against involuntary exposure to environmental noise requires special consideration of physical setting and the communication needs associated with each.

In the next subsection, the above rationale is applied to identify the maximum noise level consistent with an adequate margin of safety for the general classes of sound found most often in the environment. Certain special classes of sound, such as infrasound, ultrasound, and impulsive sounds are discussed in the final subsection.

IDENTIFICATION OF MAXIMUM EXPOSURE LEVELS TO AVOID SIGNIFICANT ADVERSE EFFECTS

Hearing

Basic Considerations

The following considerations have been applied in identifying the environmental noise levels requisite to protect the hearing of the general population. For detailed derivation, justification and references, (see Appendix C).

1. The human ear, when damaged by noise, is typically affected at the 4000 Hz frequency first, and, therefore, this frequency can be considered the most noise-sensitive frequency. The averaged frequencies of 500 Hz, 1000 Hz and 2000 Hz have traditionally been employed in hearing conservation criteria because of their importance to the hearing of speech sounds. Since there is considerable evidence that frequencies above 2000 Hz are critical to the understanding of speech in lifelike situations, and since 4000 Hz is considered the most sensitive frequency, 4000 Hz has been selected as the most important frequency to be protected in this document.

2. Changes in hearing level of less than 5 dB are generally not considered noticeable or significant.

3. As individuals approach the high end of the distribution and their hearing levels are decreased, they become less affected by noise exposure. In other words, there comes a point where one cannot be damaged by sounds which one cannot hear.

4. The noise level chosen protects against hearing loss up to and including the 96th percentile of the population, ranked according to decreasing ability to hear at 4000 Hz. Since the percentiles beyond that point are also protected (see consideration number 3), virtually the entire population is protected against incurring more than a 5 dB noise-induced permanent threshold shift (NIPTS).

Explanation of Identified Level for Hearing Loss

Taking into account the assumptions and considerations mentioned above, the 8-hour exposure level which protects virtually the entire population from greater than 5 dB NIPTS is 73 dB, (see Figure 3). Before this value of 73 dB for 8-hour exposures can be applied to the environmental situation, however, certain correction or conversion factors must be considered. These correction factors are:

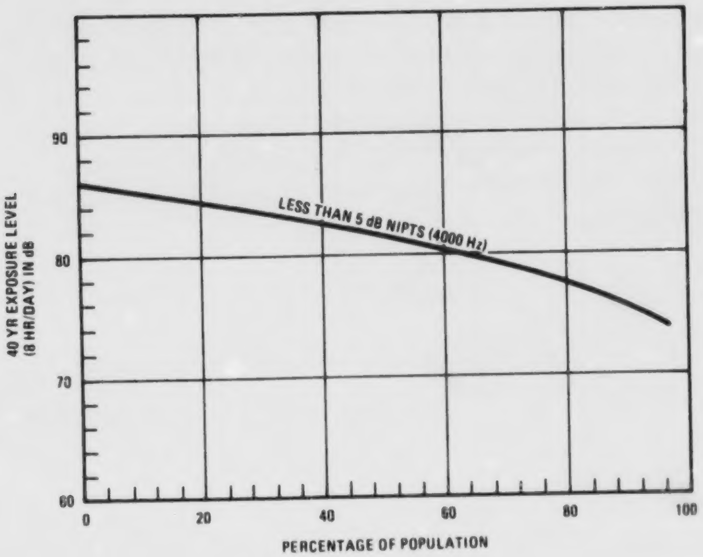

Figure 3. Percentage of Exposed Population That Will Incur No More Than 5 dB NIPTS Shown as a Function of Exposure Level. Population Ranked by Decreasing Ability to Hear at 4000 Hz. (See Appendix C for Rationale).

1. Intermittency: allows the exposure level to be 5 dB higher. This correction factor is required because most environmental noise is intermittent (not at a steady level, but below 65 dBA more than 10% of any one-hour period) and intermittent noise has been shown less damaging than continuous noise of the same L_{eq}. This correction should normally be applied except in situations that do not meet this criterion for intermittency.

2. Correction to yearly dose (250 to 365 days): requires reduction of the exposure level by 1.6 dB. All data used as the basis of Figure 3 come from occupational exposures which are only 250 days per year, whereas, this document must consider all 365 days in a year.

3. Correction to twenty-four hour day: the identified level of 73 dB is based on 8-hour daily exposures. Conversion to a 24-hour period using the equal-energy rule requires reduction of this level by 5 dB. This means that continuous sounds of a 24-hour duration must be 5 dB less intense than higher level sounds of only 8 hours duration, with the remaining 16 hours considered quiet.

Using the above corrections and conversions implies that the average 8-hour daily dose (based on a yearly average and assuming intermittent noise) should be no greater than $L_{eq(8)} = 73+5-1.6 = 76.4$ dB. Extending the duration to 24 hours would yield a value of 71.4 dB. For continuous noise, this value would be 66.4 dB. However, since environmental noise is intermittent, this level is below that which is considered necessary to protect public health and welfare. In view of possible statistical errors in the basic data, it is considered reasonable, especially with respect to a margin of safety, to round down from 71.4 dB to 70 dB. Therefore, the level of intermittent noise identified here for purposes of protection against hearing loss is:

$$L_{eq(24)} = 70 \text{ dB}$$

(For explanation of the relationship between exposures of $L_{eq(8)} = 75$ dB and $L_{eq(24)} = 70$ dB, please see page 4.)

Adequate Margin of Safety

Section 5(a)(2), as stated previously, requires an adequate margin of safety. The level identified to protect against hearing loss, is based on three margins of safety considerations:

1. The level protects at the frequency where the ear is most sensitive (4,000 Hz).
2. It protects virtually the whole population from exceeding 5 dB NIPTS.
3. It rounds off in the direction of hearing conservation (downward) to provide in part for uncertainties in analyzing the data.

Activity Interference/Annoyance

Basic Considerations

The levels of environmental noise which interfere with human activity (see Appendix D for detailed dicussion) depend upon the activity and its contextual frame of reference; i.e., they depend upon "defined areas under various conditions". The effect of activity interference is often described in terms of annoyance. However, various non-level related factors, such as attitude towards the noise source and local conditions, may influence an individual's reaction to activity interferences.

The levels which interfere with listening to a desired sound, such as speech or music, can be defined in terms of the level of interfering sound required to mask the desired sound. Such levels have been quantified for speech communication by directly measuring the interference with speech intelligibility as a function of the level of the intruding sound, relative to the level of the speech sounds.

The levels interfering with human activities which do not involve active listening have not been as well quantified relative to the level of a desired sound. These relationships are more complicated because interference caused by an intruding sound depends upon the background level and the state of the human auditor; e.g., the degree of concentration when endeavoring to accomplish a mental task, or the depth of sleep, etc. Fortunately, there is a wealth of survey data on community reaction to environmental noise which, although subject to some shortcomings when taken alone, can be used to supplement activity interference data to identify noise levels requisite to protect public health and welfare. Thus, the levels identified here primarily reflect results of research on community reaction and speech masking.

Identified Levels for Interference

The level identified for the protection of speech communication is an L_{eq} of 45 dB within the home in order to provide for 100% intelligibility of speech sounds. Allowing for the 15 dB reduction in sound level between outdoors and indoors (which is an average amount of sound attenuation that assumes partly-open windows), this level becomes an outdoor L_{eq} of 60 dB for residential areas. For outdoor voice communication, the outdoor L_{eq} of 60 dB allows normal conversation at distances up to 2 meters with 95% sentence intelligibility.

Although speech-interference has been identified as the primary interference of noise with human activities and is one of the primary reasons for adverse community reactions to noise and long-term annoyance, the 10 dB nighttime weighting (and, hence, the term L_{dn}) is applied to give adequate weight to all of the other adverse effects on activity interference. For the same reason, a 5 dB margin of safety is applied to the identified outdoor level. Therefore, the outdoor L_{dn} identified for residential areas is 55 dB. (See Appendix E for relationship of L_{eq} to L_{dn}.)

The associated interior day-night sound level within a typical home which results from outdoors is 15 dB less, or 40 dB due to the attenuation of the structure. The expected indoor daytime level for a typical neighborhood which has an outdoor L_{dn} of 55 dB is approximately 40 dB, whereas the nighttime level is approximately 32 dB (see Figure A-7). This latter value is consistent with the limited available sleep criteria [D-5]. Additionally, these indoor levels of 40 dB during the day and approximately 32 dB at night are consistent with the background levels inside the home which have been recommended by acoustical consultants as acceptable for many years, (see Table D-10).

The effects associated with an outdoor day-night sound level of 55 dB are summarized in Table 3. The summary shows that satisfactory outdoor average sentence intelligibility may be expected for normal voice conversations over distances of up to 3.5 meters; that depending on attitude and other non-level related factors, the average expected community reaction is none, although 1% may complain and 17% indicate "highly annoyed" when responding to social survey questions; and that noise is the least important factor governing attitude towards the area.

Identification of a level which is 5 dB higher than the 55 dB identified above would significantly increase the severity of the average community reaction, as well as the expected percentage of complaints and annoyance. Conversely, identification of a level 5 dB lower than the 55 dB identified above would reduce the indoor levels resulting from outdoor noise well below the typical background indoors (see Table 3) and probably make little change in annoyance since at levels below the identified level, individual attitude and life style, as well as local conditions, seem to be more important factors in controlling the resulting magnitude of annoyance or community reaction than is the absolute magnitude of the level of the intruding noise.

Accordingly, L_{dn} of 45 dB indoors and of 55 dB outdoors in residential areas are identified as the maximum levels below which no effects on public health and welfare occur due to interference with speech or other activity. These levels would also protect the vast majority of the population under most conditions against annoyance, in the absence of intrusive noises with particularly aversive content.

Adequate Margin of Safety

The outdoor environmental noise level identified in Table 3 provides a 5 dB margin of safety with respect to protecting speech communication. This is considered desirable for the indoor situation to provide for homes with less than average noise reduction or for persons speaking with less than average voice level. A higher margin of safety would be ineffective most of the time due to normal indoor activity background levels.

The 5 dB margin of safety is particularly desirable to protect the population against long-term annoyance with a higher probability than would be provided by the levels protecting indoor and outdoor speech communication capability alone. The 5 dB margin clearly shifts community response as well as subjective annoyance rating into the next lower

Table 3

SUMMARY OF HUMAN EFFECTS IN TERMS OF SPEECH COMMUNICATION, COMMUNITY REACTION, COMPLAINTS, ANNOYANCE AND ATTITUDE TOWARDS AREA ASSOCIATED WITH AN OUTDOOR DAY/NIGHT SOUND LEVEL OF 55 dB re 20 MICROPASCALS

TYPE OF EFFECT	MAGNITUDE OF EFFECT
Speech - Indoors	100% sentence intelligibility (average) with a 5 dB margin of safety
- Outdoors	100% sentence intelligibility (average) at 0.35 meters 99% sentence intelligibility (average) at 1.0 meters 95% sentence intelligibility (average) at 3.5 meters
Average Community Reaction	None evident; 7 dB below level of significant "complaints and threats of legal action" and at least 16 dB below "vigorous action" (attitudes and other non-level related factors may affect this result)
Complaints	1% dependent on attitude and other non-level related factors
Annoyance	17% dependent on attitude and other non-level related factors
Attitudes Towards Area	Noise essentially the least important of various factors

(Derived from Appendix D)

response category than would be observed for the maximum level identified with respect to speech communication alone. According to present data, this margin of safety protects the vast majority of the population against long-term annoyance by noise. It would reduce environmental noise to a level where it is least important among environmental factors that influence the population's attitude toward the environment. To define an environment that eliminates any potential annoyance by noise occasionally to some part of the population appears not possible at the present state of knowledge.

MAXIMUM EXPOSURES TO SPECIAL NOISES

Inaudible Sounds

The following sounds may occur occasionally but are rarely found at levels high enough to warrant consideration in most environments which the public occupies. For a more detailed discussion, see Appendix G.

Infrasound

Frequencies below 16 Hz are referred to as infrasonic frequencies and are not audible. Complaints associated with extremely high levels of infrasound can resemble a mild stress reaction and bizarre auditory sensations, such as pulsating and fluttering. Exposure to high levels of infrasound is rare for most individuals. Nevertheless, on the basis of existing data[2,7], the threshold of these effects is approximately 120 dB SPL (1-16 Hz). Since little information exists with respect to duration of exposure and its effects, and also since many of the data are derived from research in which audible frequencies were present in some amount, these results should be interpreted with caution.

Ultrasound

Ultrasonic frequencies are those above 20,000 Hz and are also generally inaudible. The effects of exposure to high intensity ultrasound is reported by some to be a general stress response. Exposure to high levels of ultrasound does not occur frequently. The threshold of any effects for ultrasound is 105 dB SPL[2]. Again, many of these data may include frequencies within the audible range, and results are, therefore, to be interpreted cautiously.

Impulse Noise

It is difficult to identify a single-number limit requisite to protect against adverse effects from impulse noise because it is essential to take into account the circumstances of exposure, the type of impulse, the effective duration, and the number of daily exposures, (see Appendix G).

Hearing

Review of temporary threshold shift data leads to the conclusion that the impulse noise limit requisite to prevent more than a 5 dB permanent hearing loss at 4000 Hz after 10 years of daily exposure is a peak sound pressure level (SPL) of 145 dB. This level applies in the case of isolated events, irrespective of the type, duration, or incidence at the ear. However, for duration of 25 microseconds or less, a peak level of 167 dB SPL would produce the same effect, (see Figure 4).

1. Duration Correction: When the duration of the impulse is less than 25 microseconds, no correction for duration is necessary. For durations exceeding 25 microseconds, the level should be reduced in accordance with the "modified CHABA limit" shown in Figure 4 and Figure G-1 of Appendix G.

2. Correction for Number of Impulses:

Number of impulses per day:	1	10	100	10^3	10^4	
Correction factor:	0	-10	-20	-30	-40	dB

(More detailed information is provided in Figure 4.)

Furthermore, if the average interval between repeated impulses is between 1 and 10 seconds, a third correction factor of -5 dB is applied. Thus, to prevent hearing loss due to impulse noise, the identified level is 145 dB SPL, or 167 dB peak SPL for impulses less than 25 microseconds, for one impulse daily. For longer durations or more frequent exposures, the equivalent levels are as shown in Figure 4.

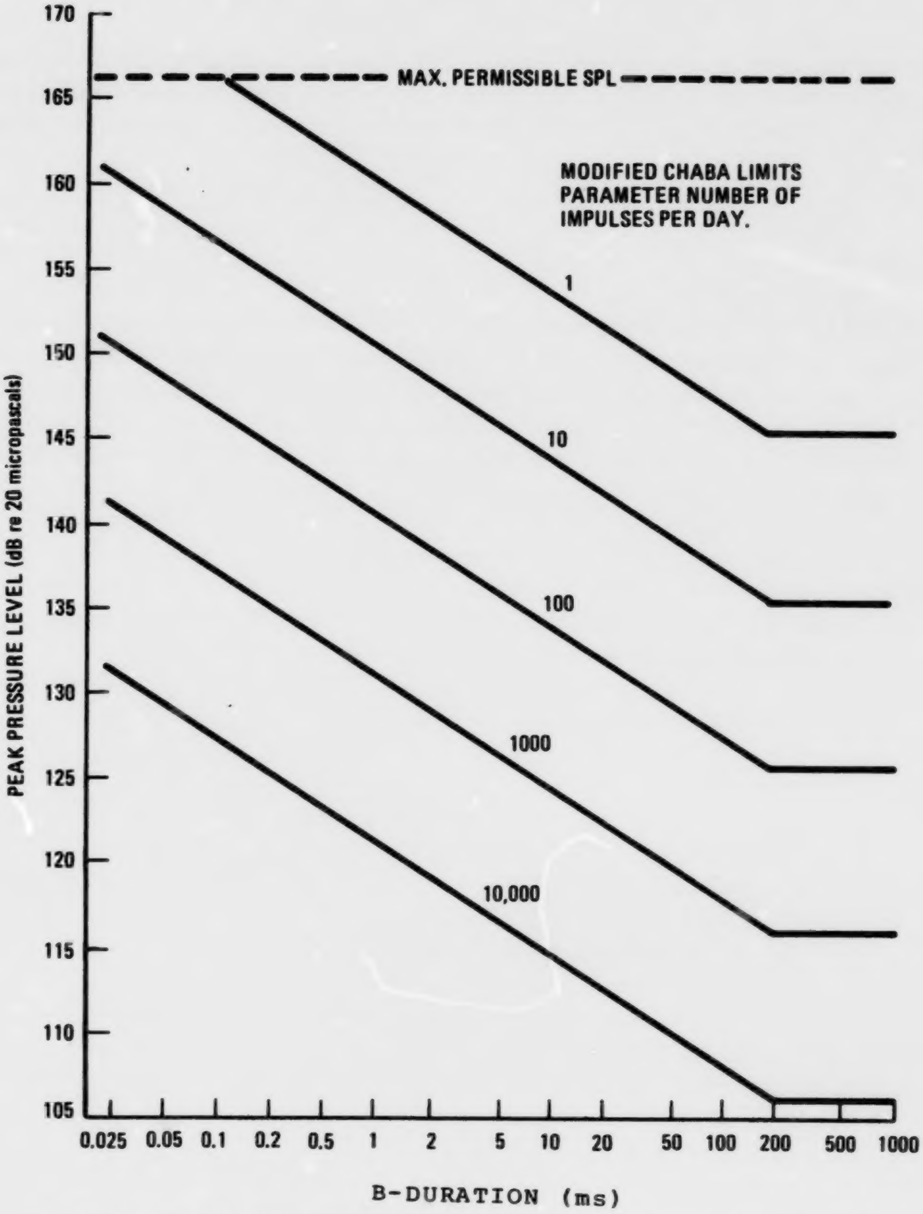

Figure 4. Set of Modified CHABA Limits for Daily Exposure to Impulse Noises Having B-Durations in the Range 25 Microseconds to 1 Second. (Parameter: number (N) of impulses per daily exposure. Criterion: NIPTS not to exceed 5 dB at 4 kHz in more than 10% of people.)

(Derived from Appendix G)

Non-Auditory Effects of Impulsive Sound

Impulses exceeding the background noise by more than about 10 dB are potentially startling or sleep-disturbing. If repeated, impulsive noises can be disturbing to some individuals if heard at all *(they may be at levels below the average noise levels).* However, no threshold level can be identified at this time; nor is there any clear evidence or documentation of any permanent effect on public health and welfare.

Sonic Booms

Little or no public annoyance is expected to result from one sonic boom during the daytime below the level of 35.91 pascals (0.75 pounds per square foot) as measured on the ground (see Appendix G). The same low probability of annoyance is expected to occur for more than one boom per day if the peak level of each boom is no greater than:

$$\text{Peak Level} = \frac{35.91}{\sqrt{N}} \text{ pascals}$$

Where N is the number of booms. This value is in agreement with the equal energy concept.

Section 4

IDENTIFIED LEVELS OF ENVIRONMENTAL NOISE IN DEFINED AREAS

IDENTIFIED LEVELS

Table 4 identifies the levels requisite to protect public health and welfare with an adequate margin of safety for both activity interference and hearing loss. The table classifies the various areas according to the primary activities that are most likely to occur in each. The following is a brief description of each classification and a discussion of the basis for the identified levels in Table 4. For a more detailed discussion of hearing loss and activity interference, see Appendices C and D.

1. Residential areas are areas where human beings live, including apartments, seasonal residences, and mobile homes, as well as year-round residences. A quiet environment is necessary in both urban and rural residential areas in order to prevent activity interference and annoyance, and to permit the hearing mechanism to recuperate if it is exposed to higher levels of noise during other periods of the day.

An indoor L_{dn} of 45 dB will permit speech communication in the home, while an outdoor L_{dn} not exceeding 55 dB will permit normal speech communication at approximately three meters. Maintenance of this identified outdoor level will provide an indoor L_{dn} of approximately 40 dB with windows partly open for ventilation. The nighttime portion of this L_{dn} will be approximately 32 dB, which should in most cases, protect against sleep interference. An $L_{eq(24)}$ of 70 dB is identified as protecting against damage to hearing.

Although there is a separate category for commercial areas, commercial living accommodations such as hotels, motels, cottages, and inns should be included in the residential category since these are places where people sleep and sometimes spend extended periods of time.

2. Commercial areas include retail and financial service facilities, offices, and miscellaneous commercial services. They do not include warehouses, manufacturing plants, and other industrial facilities, which are included in the industrial classification. Although a level for activity interference has not been identified here (see footnote a), suggestions for such levels will be found in Table D-10 of Appendix D. On the other hand, a level of $L_{eq(24)}$ of 70 dB has been identified to protect against hearing loss.

Table 4
YEARLY AVERAGE*EQUIVALENT SOUND LEVELS IDENTIFIED AS REQUISITE TO PROTECT THE PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY

		Indoor			Outdoor		
	Measure	Activity Interference	Hearing Loss Consideration	To Protect Against Both Effects (b)	Activity Interference	Hearing Loss Consideration	To Protect Against Both Effects (b)
Residential with Outside Space and Farm Residences	L_{dn}	45		45	55		55
	$L_{eq(24)}$		70			70	
Residential with No Outside Space	L_{dn}	45		45			
	$L_{eq(24)}$		70				
Commercial	$L_{eq(24)}$	(a)	70	70(c)	(a)	70	70(c)
Inside Transportation	$L_{eq(24)}$	(a)	70	(a)			
Industrial	$L_{eq(24)(d)}$	(a)	70	70(c)	(a)	70	70(c)
Hospitals	L_{dn}	45		45	55		55
	$L_{eq(24)}$		70			70	
Educational	$L_{eq(24)}$	45		45	55		55
	$L_{eq(24)(d)}$		70			70	
Recreational Areas	$L_{eq(24)}$	(a)	70	70(c)	(a)	70	70(c)
Farm Land and General Unpopulated Land	$L_{eq(24)}$				(a)	70	70(c)

Code:

a. Since different types of activities appear to be associated with different levels, identification of a maximum level for activity interference may be difficult except in those circumstances where speech communication is a critical activity. (See Figure D-2 for noise levels as a function of distance which allow satisfactory communication.)

b. Based on lowest level.

c. Based only on hearing loss.

d. An $L_{eq(8)}$ of 75 dB may be identified in these situations so long as the exposure over the remaining 16 hours per day is low enough to result in a negligible contribution to the 24-hour average, i.e., no greater than an L_{eq} of 60 dB.

Note: Explanation of identified level for hearing loss. The exposure period which results in hearing loss at the identified level is a period of 40 years.

*Refers to energy rather than arithmetic averages.

3. Transportation facilities are included so as to protect individuals using public and private transportation. Included within this classification are commercial and private transportation vehicles. Identification of a level to protect against hearing loss is the only criterion used at this time, although levels lower than an L_{eq} of 70 dB are often desirable for effective speech communication. However, because of the great variety of conditions inside transportation vehicles, and because of the desirability of speech privacy in certain situations, a level based on activity interference cannot be identified for all modes of transportation at this time.

4. Industrial areas include such facilities as manufacturing plants, warehouses, storage areas, distribution facilities, and mining operations. Only a level for hearing loss is identified due to the lack of data with respect to annoyance and activity interference. Where the noise exposure is intermittent, an $L_{eq(24)}$ of 70 dB is identified as the maximum level for protection of hearing from industrial exposure to intermittent noise. For 8-hour exposures, an $L_{eq(8)}$ of 75 dB is considered appropriate so long as the exposure over the remaining 16 hours per day is low enough to result in a negligible contribution to the 24-hour average.

5. Hospital areas include the immediate neighborhood of the hospital as well as its interior. A quiet environment is required in hospital areas because of the importance of sleep and adequate rest to the recovery of patients. The maintenance of a noise level not exceeding an L_{dn} of 45 dB in the indoor hospital environment is deemed adequate to prevent activity interference and annoyance. An outdoor L_{dn} of 55 dB should be adequate to protect patients who spend some time outside, as well as insuring an adequately protective indoor level. An $L_{eq(24)}$ of 70 dB is identified to prevent hearing loss.

6. Educational areas include classrooms, auditoriums, schools in general, and those grounds not used for athletics. The principal consideration in the education environment is the prevention of interference with activities, particularly speech communication. An indoor noise level not exceeding $L_{eq(24)}$ of 45 dB is identified as adequate to facilitate thought and communication. Since teaching is occasionally conducted outside the classroom, an outdoor $L_{eq(24)}$ of 55 dB is identified as the maximum level to prevent activity interference. To protect against hearing loss an $L_{eq(24)}$ of 70 dB is identified for both indoor and outdoor environments. As in the industrial situation, eight hours is generally the amount of time spent in educational facilities. Therefore an $L_{eq(8)}$ of 75 dB is considered appropriate to protect against hearing loss, so long as the exposure over the remaining l6 hours is low enough to result in a negligible contribution to the 24-hour average.

7. Recreational areas include facilities where noise exposure is voluntary. Included within this classification are nightclubs, theaters, stadiums, racetracks, beaches, amusement parks, and athletic fields. Since sound exposure in such areas is usually voluntary, there is seldom any interference with the desired activity. Consequently, the chief consideration is

the protection of hearing. An $L_{eq(24)}$ of 70 dB is therefore identified for intermittent noise in order to prevent hearing damage.

8. Farm and general unpopulated land primarily includes agricultural property used for the production of crops or livestock. For such areas, the primary considerations are the protection of human hearing and the prevention of adverse effects on domestic and wild animals. Protection of hearing requires that an individual's exposure to intermittent noise does not exceed $L_{eq(24)}$ of 70 dB. A separate level for the exposure of animals is not identified due to the lack of data indicating that hearing damage risk for animals is substantially different from that of humans. The unpopulated areas include wilderness areas, parks, game refuges, and other areas that are set aside to provide enjoyment of the outdoors. Although quiet is not always of paramount importance in such areas, many individuals enjoy the special qualities of serenity and tranquility found in natural areas. At this time it is not possible to identify an appropriate level to prevent activity interference and annoyance. However, when it becomes possible to set such a level, a clear distinction should be made between natural and man-made noise.

USE OF IDENTIFIED ENVIRONMENTAL NOISE LEVELS

One of the purposes of this document is to provide a basis for judgment by states and local governments as a basis for setting standards. In doing so the information contained in this document must be utilized along with other relevant factors. These factors include the balance between costs and benefits associated with setting standards at particular noise levels, the nature of the existing or projected noise problems in any particular area, the local aspirations and the means available to control environmental noise.

In order to bring these factors together, states, local governments and the public will need to evaluate in a systematic manner the following:

1. The magnitude of existing or projected noise environments in defined areas as compared with the various levels identified in this document.

2. The community expectations for noise abatement with respect to existing or projected conditions.

3. The affected elements of the public and the degree of impact of present or projected environmental noise levels.

4. The noise sources, not controlled by Federal regulations, that cause local noise problems.

5. Methods available to attack environmental noise problems (use limitations, source control through noise emission standards, compatible land use planning, etc.).

6. The costs inherent in reducing noise to certain levels and benefits achieved by doing so.

7. The availability of technology to achieve the desired noise reduction.

The levels of environmental noise identified in this report provide the basis for assessing the effectiveness of any noise abatement program. These noise levels are identified irrespective of the nature of any individual noise source. One of the primary purposes of identifying environmental noise levels is to provide a basis by which noise source emission regulations, human exposure standards, land use planning, zoning, and building codes may be assessed, as to the degree with which they protect the public health and welfare with respect to noise. Such regulatory action must consider technical feasibility and economic reasonableness, the scale of time over which results can be expected, and the specific problems of enforcement. In the process of balancing these conflicting elements, the public health and welfare consequence of any specific decision can be determined by comparing the resultant noise environment against the environmental noise levels identified in this report.

REFERENCES

1. Noise Control Act of 1972, Public Law 92-574, 92 Congress, HR 11021, October 27, 1972.

2. Public Health and Welfare Criteria for Noise, EPA, July 27, 1973, 550/9-73-002.

3. "Report to the President and Congress on Noise," EPA, NRC 500.1, December 31, 1971.

4. "Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure," EPA Report NTID 73.4, 1973.

5. Proceedings of the Conference on Noise as a Public Health Problem, EPA Report 550/9-73-008, 1973.

6. Seacord, D.F., *J. Acoustical Society of America*, 12:183, 1940.

7. Johnson, D., "Various Aspects of Infrasound," presented at the Colloquin on Infrasound, Centre National de la Recherche Scientifique Paris, September 1973.

GLOSSARY

AUDIBLE RANGE (OF FREQUENCY) (AUDIO-FREQUENCY RANGE). The frequency range 16 Hz to 20,000 Hz (20 kHz). *Note:* This is conventionally taken to be the normal frequency range of human hearing.

AUDIOMETER. An instrument for measuring the threshold or sensitivity of hearing.

AUDIOMETRY. The measurement of hearing.

BROAD-BAND NOISE. Noise whose energy is distributed over a broad range of frequency (generally speaking, more than one octave).

CONTINUOUS NOISE. On-going noise whose intensity remains at a measurable level (which may vary) without interruption over an indefinite period or a specified period of time.

DEAFNESS. 100 percent impairment of hearing associated with an organic condition. *Note:* This is defined for medical and cognate purposes as the hearing threshold level for speech or the average hearing threshold level for pure tones of 500, 1000 and 2000 Hz in excess of 92 dB.

EQUIVALENT SOUND LEVEL. The level of a constant sound which, in a given situation and time period, has the same sound energy as does a time-varying sound. Technically, equivalent sound level is the level of the time-weighted, mean square, A-weighted sound pressure. The time interval over which the measurement is taken should always be specified.

ENVIRONMENTAL NOISE. By Sec 3(11) of the Noise Control Act of 1972, the term "environmental noise" means the intensity, duration, and character of sounds from all sources.

HEARING LEVEL. The difference in sound pressure level between the threshold sound for a person (or the median value or the average for a group) and the reference sound pressure level defining the ASA standard audiometric threshold (ASA: 1951). *Note:* The term is now commonly used to mean hearing threshold level (qv). Units: decibels.

HEARING LOSS. Impairment of auditory sensitivity: an elevation of a hearing threshold level.

HEARING THRESHOLD LEVEL. The amount by which the threshold of hearing for an ear (or the average for a group) exceeds the standard audiometric reference zero (ISO, 1964; ANSI, 1969). Units: decibels.

IMPULSE NOISE (IMPULSIVE NOISE). Noise of short duration (typically, less than one second) especially of high intensity, abrupt onset and rapid decay, and often rapidly changing spectral composition. *Note:* Impulse noise is characteristically associated with such sources as explosions, impacts, the discharge of firearms, the passage of super-sonic aircraft (sonic boom) and many industrial processes.

INFRASONIC. Having a frequency below the audible range for man (customarily deemed to cut off at 16 Hz).

INTERMITTENT NOISE. Fluctuating noise whose level falls once or more times to low or unmeasurable values during an exposure. In this document intermittent noise will mean noise that is below 65 dBA at least 10% of any 1 hour period.

NOISE EXPOSURE. The cumulative acoustic stimulation reaching the ear of the person over a specified period of time (e.g., a work shift, a day, a working life, or a lifetime).

NOISE HAZARD (HAZARDOUS NOISE). Acoustic stimulation of the ear which is likely to produce noise-induced permanent threshold shift in some of a population.

NOISE-INDUCED PERMANENT THRESHOLD SHIFT (NIPTS). Permanent threshold shift caused by noise exposure, corrected for the effect of aging (presbyacusis).

NOISE-INDUCED TEMPORARY THRESHOLD SHIFT (NITTS). Temporary threshold shift caused by noise exposure.

NON-VOLUNTARY EXPOSURE TO ENVIRONMENTAL NOISE. The exposure of an individual to sound which (1) the individual cannot avoid or (2) the sound serves no useful purpose (e.g., the exposure to traffic noise or exposure to noise from a lawn mower).

OCCUPATIONAL EXPOSURE TO ENVIRONMENTAL NOISE. The noise exposure of an individual defined under P.L. 91-596, Occupational Safety and Health Act of 1970.

OTOLOGICALLY NORMAL. Enjoying normal health and freedom from all clinical manifestations and history of ear disease or injury; and having a patent (wax-free) external auditory meatus.

PEAK SOUND PRESSURE. The absolute maximum value (magnitude) of the instantaneous sound pressure occurring in a specified period of time.

PRESBYACUSIS (PRESBYCUSIS). Hearing loss, chiefly involving the higher audiometric frequencies above 3000 Hz, ascribed to advancing age.

RISK. That percentage of a population whose hearing level, as a result of a given influence, exceeds the specified value, minus that percentage whose hearing level would have exceeded the specified value in the absence of that influence, other factors remaining the same. *Note:* The influence may be noise, age, disease, or a combination of factors.

SOUND LEVEL. The quantity in decibels measured by a sound level meter satisfying the requirements of American National Standards Specification for Sound Level Meters S1.4-1971. Sound level is the frequency-weighted sound pressure level obtained with the standardized dynamic characteristic "fast" or "slow" and weighting A, B, or C; unless indicated otherwise, the A-weighting is understood. The unit of any sound level is the decibel, having the unit symbol dB.

SOUND EXPOSURE LEVEL. The level of sound accumulated over a given time interval or event. Technically, the sound exposure level is the level of the time-integrated mean square A-weighted sound for a stated time interval or event, with a reference time of one second.

SOUND PRESSURE LEVEL. In decibels, 20 times the logarithm to the base ten of the ratio of a sound pressure to the reference sound pressure of 20 micropascals (20 micronewtons per square meter). In the absence of any modifier, the level is understood to be that of a mean-square pressure.

SPEECH DISCRIMINATION. The ability to distinguish and understand speech signals.

TEMPORARY THRESHOLD SHIFT (TTS). That component of threshold shift which shows a progressive reduction with the passage of time after the apparent cause has been removed.

THRESHOLD OF HEARING (AUDIBILITY). The minimum effective sound pressure level of an acoustic signal capable of exciting the sensation of hearing in a specified proportion of trials in prescribed conditions of listening.

ULTRASONIC. Having a frequency above the audible range for man (conventionally deemed to cut off at 20,000 Hz).

APPENDIX A

EQUIVALENT SOUND LEVEL AND ITS RELATIONSHIP TO OTHER NOISE MEASURES

Appendix A

EQUIVALENT SOUND LEVEL AND ITS RELATIONSHIP TO OTHER NOISE MEASURES

DEVELOPMENT OF EQUIVALENT SOUND LEVEL

The accumulated evidence of research on human response to sound indicates clearly that the magnitude of sound as a function of frequency and time are basic indicators of human response to sound. These factors are reviewed here, and it is concluded that it is not necessary to invent a new concept for the purpose of identifying levels of environmental noise.

Magnitude

Sound is a pressure fluctuation in the air; the magnitude of the sound describes the physical sound in the air; (loudness, on the other hand, refers to how people judge the sound when they hear it). Magnitude is stated in terms of the amplitude of the pressure fluctuation. The range of magnitude between the faintest audible sound and the loudest sound the ear can withstand is so enormous (a ratio of about 1,000,000 to 1) that it would be very awkward to express sound pressure fluctuations directly in pressure units. Instead, this range is "compressed" by expressing the sound pressure on a logarithmic scale. Thus, sound is described in terms of the sound pressure level (SPL), which is ten times the common logarithm of the ratio of the square of the sound pressure in question to the square of a (stated or understood) reference sound pressure, almost always 20 micropascals.* Or, in mathematical terms, sound pressure level L expressed in decibels is:

$$L = 10 \log \left(\frac{p^2}{p_o^2}\right) \qquad \text{(Eq. A-1)}$$

where p is the pressure fluctuation and p_o is the reference pressure.

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*One pascal = one newton per square meter.

Frequency Characteristics of Noise

The response of human beings to sound depends strongly on the frequency of sound. In general, people are less sensitive to sounds of low frequency, such as 100 hertz (Hz)*, than to sounds at 1000 Hz; also at high frequencies such as 8000 Hz, sensitivity decreases. Two basic approaches to compensate for this difference in response to different frequencies are (1) to segment the sound pressure spectrum into a series of contiguous frequency bands by electrical filters so as to display the distribution of sound energy over the frequency range; or (2) to apply a weighting to the overall spectrum in such a way that the sounds at various frequencies are weighted in much the same way as the human ear hears them.

In the first approach a sound is segmented into sound pressure levels in 24 different frequency bands, which may be used to calculate an estimate of the "loudness" or "noisiness" sensation which the sound may be expected to cause. This form of analysis into bands is usually employed when detailed engineering studies of noise sources are required. It is much too complicated for monitoring noise exposure.

To perform such analysis, especially for time-varying sounds, requires a very complex set of equipment. Fortunately, much of this complication can be avoided by using approach 2, i.e., by the use of a special electrical weighting network in the measurement system. This network weights the contributions of sounds of different frequency so that the response of the average human ear is simulated. Each frequency of the noise then contributes to the total reading by an amount approximately proportional to the subjective response associated with that frequency. Measurement of the overall noise with a sound level meter incorporating such a weighting network yields a single number, such as the A-weighted Sound Level, or simply A-level, in decibels. For zoning and monitoring purposes, this marks an enormous simplification. For this reason, the A-level has been adopted in large-scale surveys of city noise coming from a variety of sources. It is widely accepted as an adequate way to deal with the ear's differing sensitivity to sounds of different frequency, including assessment of noise with respect to its potential for causing hearing loss. Despite the fact that more detailed analysis is frequently required for engineering noise control, the results of such noise control are adequately described by the simple measure of sound level.

One difficulty in the use of a weighted sound level is that psychoacoustic judgment data indicate that effects of tonal components are sometimes not adequately accounted for by a simple sound level. Some current ratings attempt to correct for tonal components;

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*Hertz is the international standard unit of frequency, until recently called cycles per second; it refers to the number of pressure fluctuations per second in the sound wave.

for example, in the present aircraft noise certification procedures, "Noise Standards: Aircraft Type Certification," FAR Part 36, the presence of tones is identified by a complex frequency analysis procedure. If the tones protrude above the adjacent random noise spectrum, a penalty is applied beyond the direct calculation of perceived noise level alone. However, the complexities involved in accounting for tones exceed practicable limits for monitoring noise in the community or other defined areas. Consequently, EPA concludes that, where appropriate, standards for new products will address the problem of tones in such a way that manufacturers will be encouraged to minimize them and, thus, ultimately they will not be a significant factor in environmental noise.

With respect to both simplicity and adequacy for characterizing human response, a frequency-weighted sound level should be used for the evaluation of environmental noise. Several frequency weightings have been proposed for general use in the assessment of response to noise, differing primarily in the way sounds at frequencies between 1000 and 4000 Hz are evaluated. The A-weighting, standardized in current sound level meter specifications, has been widely used for transportation and community noise description.[A-1] For many noises the A-weighted sound level has been found to correlate as well with human response as more complex measures, such as the calculated perceived noise level or the loudness level derived from spectral analysis.[A-2] However, psychoacoustic research indicates that, at least for some noise signals, a different frequency weighting which increases the sensitivity to the 1000-4000 Hz region is more reliable.[A-3] Various forms of this alternative weighting function have been proposed; they will be referred to here as the type "D-weightings". None of these alternative weightings has progressed in acceptance to the point where a standard has been approved for commercially available instrumentation.

It is concluded that a frequency-weighted sound pressure level is the most reasonable choice for describing the magnitude of environmental noise. In order to use available standardized instrumentation for direct measurement, the A frequency weighting is the only suitable choice at this time.* The indication that a type D-weighting might ultimately be more suitable than the A-weighting for evaluating the integrated effects of noise on people suggests that at such time as a type D-weighting becomes standardized and available in commercial instrumentation, its value as the weighting for environmental noise should be considered to determine if a change from the A-weighting is warranted.

Time Characteristics of Noise

The dominant characteristic of environmental noise is that it is not steady—at any particular location the noise usually fluctuates considerably, from quiet at one instant to loud the next. Thus, one cannot simply say that the noise level at a given location or that experienced by a person at that location is "so many decibels" unless a suitable method is used to average the time-varying levels. To describe the noise completely requires a statistical approach. Consequently, one should consider the noise *exposure* which is received by an individual moving through different noisy spaces. This exposure is related to the whole time-varying pattern of sound levels. Such a noise exposure can be described by the cumulative distribution of sound levels, showing exactly what percent of the whole observation period each level was exceeded.

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*All sound levels in this report are A-weighted sound pressure levels in decibels with reference to 20 micropascals.

A complete description of the noise exposure would distinguish between daytime, evening and nighttime, and between weekday and weekend noise level distributions. It would also give distributions to show the difference between winter and summer, fair weather and foul.

The practical difficulty with the statistical methodology is that it yields a large number of statistical parameters for each measuring location; and even if these were averaged over more or less homogeneous neighborhoods, it still would require a large set of numbers to characterize the noise exposure in that neighborhood. It is literally impossible for any such array of numbers to be effectively used either in an enforcement context or to map existing noise exposure baselines.

It is essential, therefore, to look further for a suitable single-number measure of noise exposure. Note that the ultimate goal is to characterize with reasonable accuracy the noise exposure of whole neighborhoods (within which there may actually exist a fairly wide range of noise levels), so as to prevent extremes of noise exposure at any given time, and to detect unfavorable trends in the future noise climate. For these purposes, pinpoint accuracy and masses of data for each location are not required, and may even be a hindrance, since one could fail to see the forest for the trees.

A number of methodologies for combining the noise from both individual events and quasi-steady state sources into measures of cumulative noise exposure have been developed in this country and in other developed nations, e.g., Noise Exposure Forecast, Composite Noise Rating, Community Noise Equivalent Level, Noise and Number Index, and Noise Pollution Level. Many of these methodologies, while differing in technical detail (primarily in the unit of measure for individual noise events), are conceptually similar and correlate fairly well with each other. Further, using any one of these methodologies, the relationships between cumulative noise exposure and community annoyance[A-4,A-5] also correlate fairly well. It is therefore unnecessary to invent a new concept for the purpose of identifying levels of environmental noise. Rather, it is possible to select a consistent measure that is based on existing scientific and practical experience and methodology and which meets the criteria presented in Section 2 of the body of this document. Accordingly the Environmental Protection Agency has selected the Equivalent Sound Level (L_{eq}) for the purpose of identifying levels of environmental noise.

Equivalent Sound Level is formulated in terms of the equivalent *steady* noise level which in a stated period of time would contain the same noise energy as the time-varying noise during the same time period.

The mathematical definition of L_{eq} for an interval defined as occupying the period between two points in time t_1 and t_2 is:

$$L_{eq} = 10 \log \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2(t)}{p_o^2} \, dt \right] \qquad \text{(Eq. A-2)}$$

where $p(t)$ is the time varying sound pressure and p_o is a reference pressure taken as 20 micropascals.

The concept of Equivalent Sound Level was developed in both the United States and Germany over a period of years. Equivalent level was used in the 1957 original Air Force Planning Guide for noise from aircraft operations,[A-6] as well as in the 1955 report[A-7] on criteria for short-time exposure of personnel to high intensity jet aircraft noise, which was the forerunner of the 1956 Air Force Regulation[A-8] on "Hazardous Noise Exposure". A more recent application is the development of CNEL (Community Noise Equivalent Level) measure for describing the noise environment of airports. This measure, contained in the Noise Standards, Title 4, Subchapter 6, of the California Administrative Code (1970) is based upon a summation of L_{eq} over a 24-hour period with weightings for exposure during evening and night periods.

The Equivalent Noise Level was introduced in 1965 in Germany as a rating specifically to evaluate the impact of aircraft noise upon the neighbors of airports.[A-9] It was almost immediately recognized in Austria as appropriate for evaluating the impact of street traffic noise in dwellings[A-10] and in schoolrooms.[A-11] It has been embodied in the National Test Standards of both East Germany[A-12] and West Germany[A-13] for rating the subjective effects of fluctuating noises of all kinds, such as from street and road traffic, rail traffic, canal and river ship traffic, aircraft, industrial operations (including the noise from individual machines), sports stadiums, playgrounds, etc. It is the rating used in both the East German[A-14] and West German[A-15] standard guidelines for city planning. It was the rating that proved to correlate best with subjective response in the large Swedish traffic noise survey of 1966-67. It has come into such general use in Sweden for rating noise exposure that commercial instrumentation is currently available for measuring L_{eq} directly; the lightweight unit is small enough to be held in one hand and can be operated either from batteries or an electrical outlet.[A-16]

The concept of representing a fluctuating noise level in terms of a steady noise having the same energy content is widespread in recent research, as shown in the EPA report on Public Health and Welfare Criteria for Noise (1973). There is evidence that it accurately describes the onset and progress of permanent noise-induced hearing loss,[A-17] and substantial evidence to show that it applies to annoyance in various circumstances.[A-18] The concept is borne out by Pearsons' experiments[A-19] on the trade-off of level and duration of a noisy event and by numerous investigations of the trade-off between number of events and noise level in aircraft flyovers.[A-20] Indeed, the Composite Noise Rating[A-21] is a formulation of L_{eq}, modified by corrections for day vs. night operations. The concept is embodied in several recommendations of the International Standards Organization, for assessing the noise from aircraft,[A-22] industrial noise as it affects residences,[A-23] and hearing conservation in factories.[A-24]

COMPUTATION OF EQUIVALENT SOUND LEVEL

In many applications, it is useful to have analytic expressions for the equivalent sound level L_{eq} in terms of simple parameters of the time-varying noise signal so that the integral does not have to be computed. It is often sufficiently accurate to approximate a complicated time-varying noise level with simple time patterns. For example, industrial noise can often be considered in terms of a specified noise level that is either on or off as a function of time. Similarly, individual aircraft or motor vehicle noise events can be considered to exhibit triangular time patterns that occur intermittently during a period of observation. (Assuming an aircraft flyover time pattern to be triangular in shape instead of shaped like a "normal distribution function" introduces an error of, at worst, 0.8 dB). Other noise histories can often be approximated with trapezoidal time pattern shapes.

The following sections provide explicit analytic expressions for estimating the equivalent sound level in terms of such time patterns, and graphic design charts are presented for easy application to practical problems. Most of the design charts are expressed in terms of the amount (ΔL) that the level (L) of the new noise source exceeds an existing background noise level, L_b. ($\Delta L = L - L_b$). This background noise may be considered as the equivalent sound level that existed before the introduction of the new noise, provided that its fluctuation is small relative to the maximum value of the new noise level.

Constant Level Noise - Steady or Intermittent

The L_{eq} for a continuous noise having a constant value of L_{max} is

$L_{eq} = L_{max}$, which is derived from

$$L_{eq} = 10 \log \frac{1}{T} \int_{0}^{T} 10 \left(\frac{L_{max}}{10}\right) dt = L_{max} \qquad \text{(dB)} \qquad \text{(Eq. A-3)}$$

When L_{max} is intermittently on during the time period T for a fraction x of the total time, with a background noise level L_b present for the time fraction (1-x), L_{eq} is given by:

$$L_{eq} = L_b + 10 \log \left[(1-x) + x \left(10^{\frac{\Delta L}{10}}\right) \right] \qquad \text{(dB)} \qquad \text{(Eq. A-4)}$$

where $\Delta L = L_{max} - L_b$. This pattern is illustrated and the expression is plotted in Figure A-1 for various values of L and x. For values of L_{max} that are 10 dB or more higher than L_b, L_{eq} is approximated quite accurately by:

$$L_{eq} = L_{max} + 10 \log x \qquad \text{(dB)} \qquad \text{(Eq. A-5)}$$

Except in extreme cases as noted on the graph. An hourly equivalent sound level (L_h) can be computed from the last equation with the integration time (T) equal to 3600 seconds (1 hour). An example of the relationship between L_h and L_{max} as a function of pulse duration τ for $L_{max} - L_b$ greater than 10 is given in Figure A-2. These results may be described by:

$$L_h = L_{max} + 10 \log \tau - 35.6 \qquad \text{(dB)} \qquad \text{(Eq. A-6)}$$

for $(L_{max} - L_b) > 10$

Triangular Time Patterns

The equivalent sound level for a single triangular time pattern having a maximum value of L_{max} and rising from a background level of L_b is given by:

$$L_{eq} = L_b + 10 \log \left[\frac{10}{2.3\Delta L} \left(10^{\frac{\Delta L}{10}} - 1\right) \right] \qquad \text{(dB)} \qquad \text{(Eq. A-7)}$$

where again $\Delta L = L_{max} - L_b$. When ΔL is greater than 10 dB, the following approximation for L_{eq} is quite accurate:

$$L_{eq} = L_{max} - 10 \log \frac{2.3\Delta L}{10} \qquad \text{(dB)} \qquad \text{(Eq. A-8)}$$

Except in extreme cases as noted on the graph. The value of L_{eq} for a series of n identical triangular time patterns having maximum levels of L_{max} is given by:

$$L_{eq} = L_b + 10 \log \left[1 + \frac{n\tau}{T} \left(\frac{10^{\frac{\Delta L}{10}} - 1}{2.3} - \frac{\Delta L}{10} \right) \right] \qquad \text{(dB)} \qquad \text{(Eq. A-9)}$$

Where the duration between (L_{max} - 10 dB) points* is τ seconds, the background level is L_b, and the total time period is T. (See Figure A-3). A design chart for determining L_{eq} for different values of ΔL as a function of $n\tau$ per hour is provided in Figure A-3.

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*The duration for which the noise level is within 10 dB of L_{max}; also called the "10 dB down" duration.

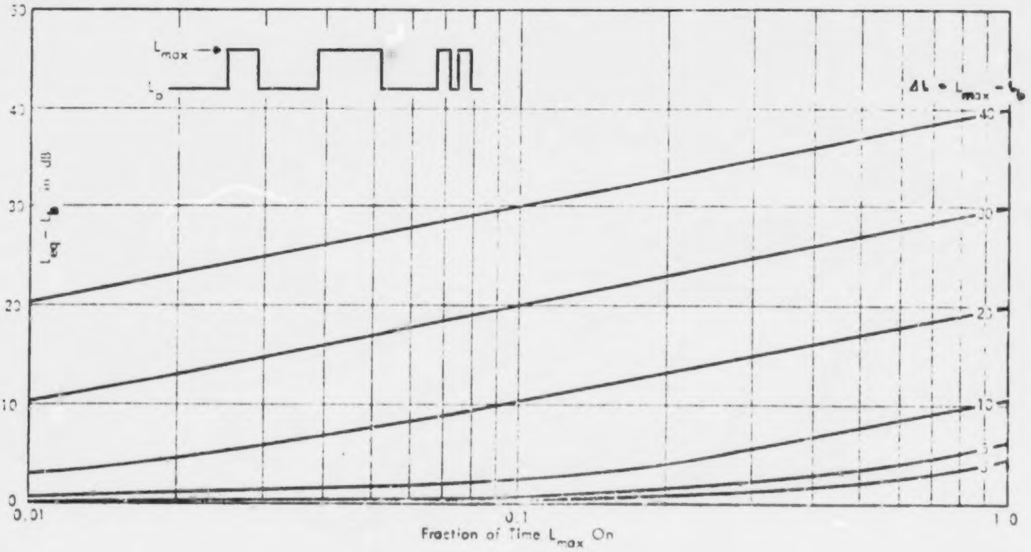

Figure A-1. L_{eq} for Intermittent L_{max} Added to L_b A-25

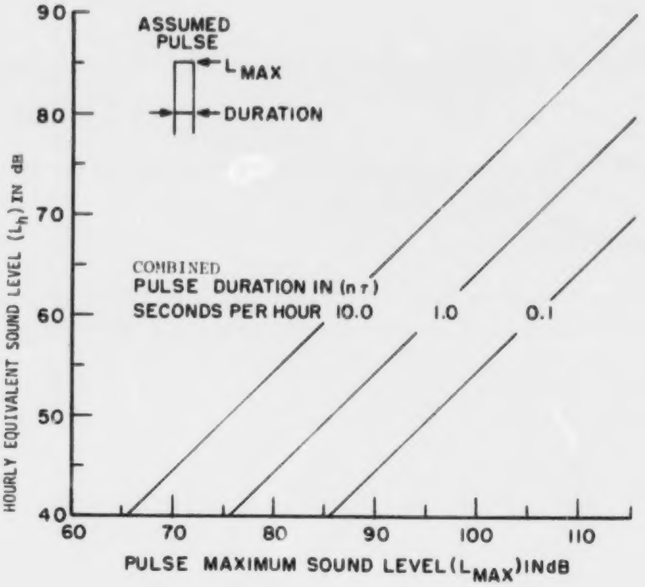

Figure A-2. Hourly Equivalent Sound Level as a Function of Pulse Duration and Maximum Sound Level for One Pulse per Hour or a Succession of n Shorter Pulses Having a Total of the Indicated Duration During One Hour. (Background sound level less than 30 dB). (Derived from Equation A-5).

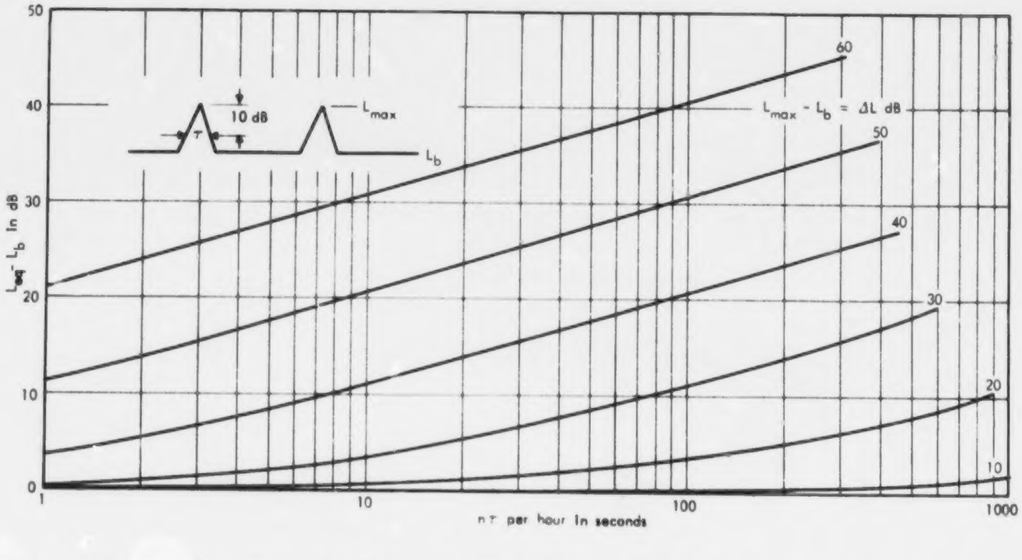

Figure A-3. L_{eq} for a Repeated Series of n Triangular Signals Overlaid on a Background Level of L_b dB and τ = Duration at (L_{max}-10) dB in Seconds.[A-25] (See Equation A-9).

An approximation to equation (A-9) for cases where L is greater than 10 dB is given by:

$$L_{eq} = L_{max} + 10 \log \frac{n\tau}{2.3T} \qquad \text{(dB)} \qquad \text{(Eq. A-10)}$$

This equation yields fairly good results except in extreme cases as can be seen in the graph.

Trapezoidal Time Patterns

The equivalent sound level, L_{eq}, for a trapezoidal time pattern having maximum level of L_{max}, background level L_b, duration between (L_{max} - 10 dB) points of τ and duration at L_{max} of ξ is given by

$$L_{eq} = 10 \log \left(\frac{1}{\frac{(\tau - \xi)\,\Delta L}{10} + \frac{\xi}{2}} \right) \left[10^{\frac{L_b}{10}} \left(\frac{(\tau - \xi)}{2.3} \right) \left(10^{\frac{\Delta L}{10}} - 1 \right) + 10^{\frac{L_{max}}{10}} \left(\frac{\xi}{2} \right) \right] \qquad \text{(dB)} \qquad \text{(Eq. A-11)}$$

The approximation to L_{eq} when ΔL is greater than 10 dB, for ξ small compared to τ, is:

$$L_{eq} = L_{max} - \frac{2.3\ \Delta L}{10} + 10 \log \xi \qquad \text{(dB)} \qquad \text{(Eq. A-12)}$$

This equation yields adequate results except in extreme cases as noted on the graph. Noting the similarity between equations (A-5) (A-8), and (A-12), one can approximate L_{eq} for a series of trapezoidal pulses by suitably combining design data from Figure A-1 and A-3. That is, the approximate L_{eq} for a series of n trapezoidal pulses is obtained by the L_{eq} value for triangular pulses plus an additional term equal to 10 log n, e.g.,

$$L_{eq} = L_{max} + 10 \log \frac{n\tau}{2.3T} + 10 \log n\xi \qquad \text{(dB)} \qquad \text{(Eq. A-13)}$$

Time Patterns of Noise Having a Normal Statistical Distribution

Many cases of noise exposures in communities have a noise level distribution that may be closely approximated by a normal statistical distribution. The equivalent sound level for the distribution can be described simply in terms of its mean value, which for a normal distribution is L_{50}, and the standard deviation (s) of the noise level distribution:

$$L_{eq} = L_{50} + 0.115\,s^2 \qquad \text{(dB)} \qquad \text{(Eq. A-14)}$$

A design chart showing the difference between L_{eq} and L_{50} as a function of the standard deviation is provided in Figure A-4.

It is often of interest to know which percentile level of a normal distribution is equal in magnitude to the L_{eq} value for the distribution. A chart providing this relationship as a function of the standard deviation of the distribution is provided in Figure A-5.

Various noise criteria in use for highway noise are expressed in terms of the L_{10} value. For a normal distribution, the L_{10} value is specified in terms of the median and standard deviation by the expression $L_{10} = L_{50} + 1.28\,s$. The difference between L_{10} and L_{eq} is given by $L_{10} - L_{eq} = 1.28\,s - 0.115\,s^2$. This expression is plotted as a function of s in Figure A-6.

It should be noted that traffic noise does not always yield a normal distribution of noise levels, so caution should be used in determining exact differences between L_{eq} and L_{10}.

RELATIONSHIPS BETWEEN DAYTIME AND NIGHTTIME EQUIVALENT SOUND LEVELS

The day-night sound level (L_{dn}) was defined as the equivalent A-weighted sound level during a 24-hour time period with a 10 decibel weighting applied to the equivalent sound level during the nighttime hours of 10 p.m. to 7 a.m. This may be expressed by the equation:

$$L_{dn} = 10 \log \frac{1}{24} \left[\left[15(10^{L_d/10}) + 9(10^{\frac{L_n+10}{10}}) \right] \right] \qquad \text{(dB)} \qquad \text{(Eq. A-15)}$$

where

L_d = L_{eq} for the daytime (0700-2200 hours)

and

L_n = L_{eq} for the nighttime (2200-0700 hours).

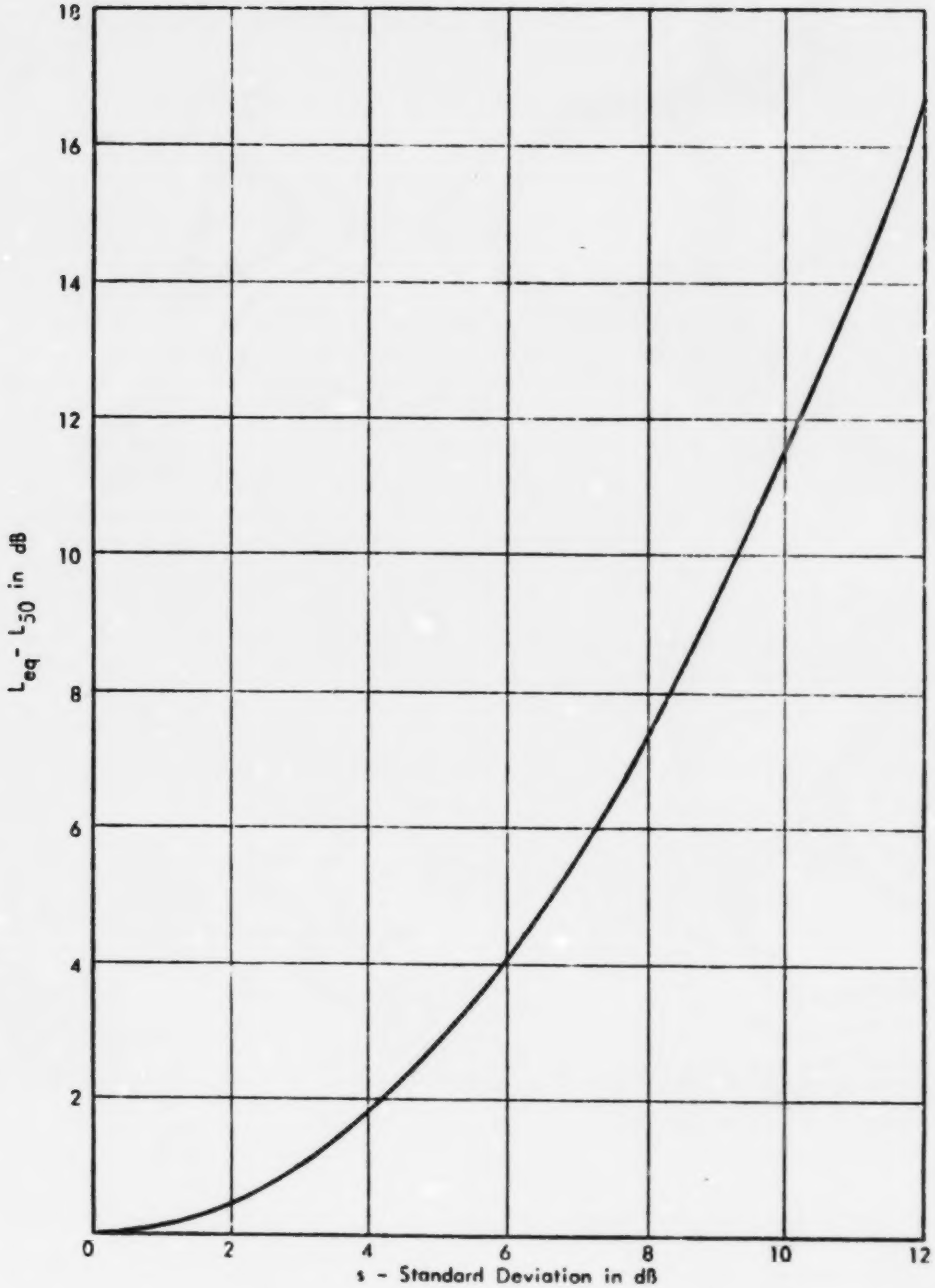

Figure A-4. Difference Between L_{eq} and L_{50} for a Normal Distribution Having Standard Deviation of s.[A-25] (See Equation A-14).

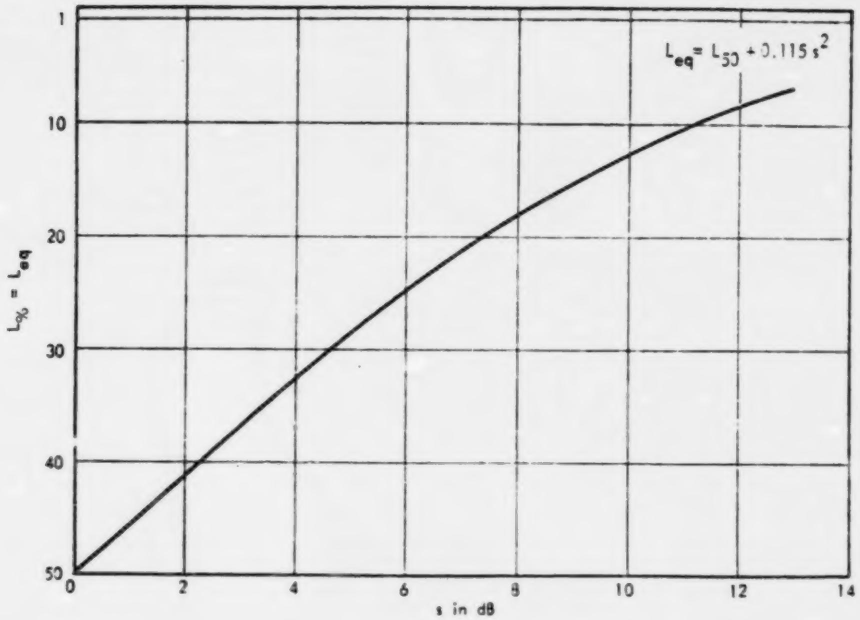

Figure A-5. Percentile of a Normal Distribution that is Equal to L_{eq}[A-25] (See Equation A-14 and Probability Function).

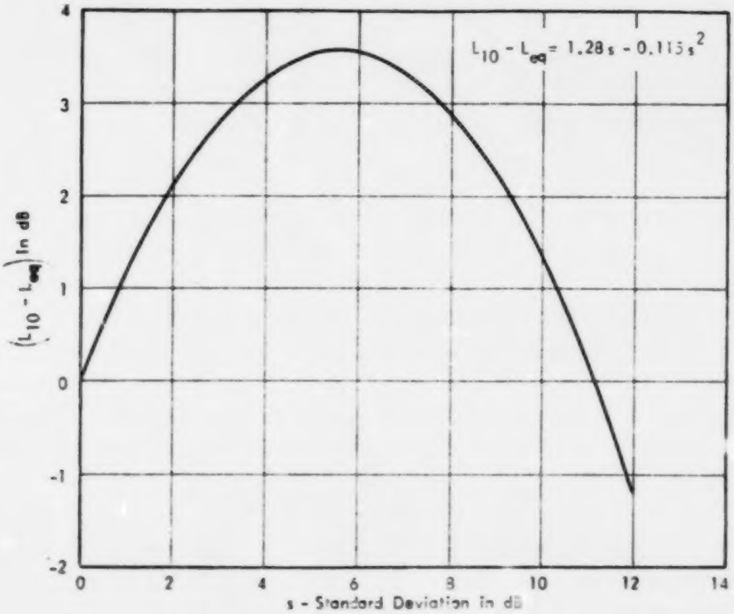

Figure A-6. Difference Between L_{10} and L_{eq} for a Normal Distribution[A-25]

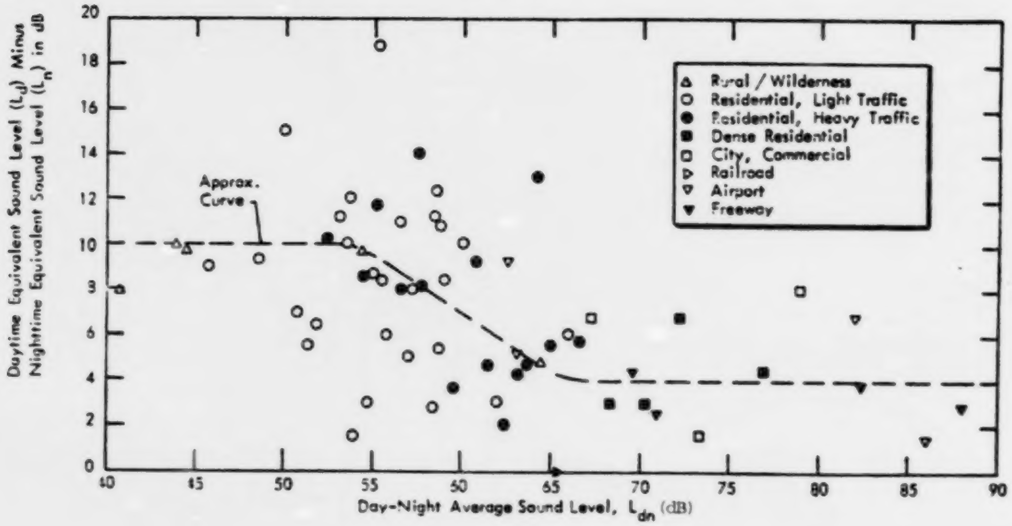

Figure A-7. Comparison of the Difference Between Day and Night Values of the Equivalent Sound Level with the Day-Night Average Sound Level, L_{dn}[A-25]

The effect of the weighting may perhaps be more clearly visualized if it is thought of as a method that makes all levels measured at night 10 dB higher than they actually are. Thus, as an example, if the noise level is a constant 70 dB all day and a constant 60 dB all night, L_{dn} would be 70 dB.

Methods for accounting for the differences in interference or annoyance between daytime/nighttime exposures have been employed in a number of different noise assessment methods around the world.[A-5] The weightings applied to the nondaytime periods differ slightly among the different countries but most of them weight night activities on the order of 10 dB;[A-24] the evening weighting if used is 5 dB. The choice of 10 dB for the nighttime weighting made in Section 2 was predicated on its extensive prior usage, together with an examination of the diurnal variation in environmental noise. This variation is best illustrated by comparing the difference between L_d and L_n as a function of L_{dn} over the range of environmental noise situations.

Data from 63 sets of measurements were available in sufficient detail that such a comparison could be made. These data are plotted in Figure A-7. The data span noise environments ranging from the quiet of a wilderness area to the noisiest of airport and highway environments. It can be seen that, at the lowest levels (L_{dn} around 40-55 dB),

L_d is the controlling element in determining L_{dn}, because the nighttime noise level is so much lower than that in the daytime. At higher L_{dn} levels (65-90 dB), the values of L_n are not much lower than those for L_d; thus, because of the 10 dB nighttime weighting, L_n will control the value of L_{dn}.

The choice of the 10 dB nighttime weighting in the computation of L_{dn} has the following effect: In low noise level environments below L_{dn} of approximately 55 dB, the natural drop in L_n values is approximately 10 dB, so that L_d and L_n contribute about equally to L_{dn}. However, in high noise environments, the night noise levels drop relatively little from their daytime values. In these environments, the nighttime weighting applies pressure towards a round-the-clock reduction in noise levels if the noise criteria are to be met.

The effect of a nighttime weighting can also be studied indirectly by examining the correlation between noise measure and observed community response in the 55 community reaction cases presented in the EPA report to Congress of 1971.[A-1] The data have a standard deviation of 3.3 dB when a 10 dB nighttime penalty is applied, but the correlation worsens (std. dev. = 4.0 dB) when no nighttime penalty is applied. However, little difference was observed among values of the weighting ranging between 8 and 12 dB. Consequently, the community reaction data support a weighting of the order of 10 dB but they cannot be utilized for determining a finer gradation. Neither do the data support "three-period" in preference to "two-period" days in assigning nondaytime noise penalties.

COMPARISON OF DAY-NIGHT SOUND LEVEL WITH OTHER MEASURES OF NOISE USED BY FEDERAL AGENCIES

The following subsections compare the day-night sound level with three measures utilized for airport noise, CNR, NEF, and CNEL, the HUD Guideline Interim Standards and the Federal Highway Administration standards:

Comparison of L_{dn} with Composite Noise Rating (CNR), Noise Exposure Forecast (NEF), and Community Noise Equivalent Level (CNEL)

CNR, NEF, and CNEL are all currently used expressions for weighted, accumulated noise exposure. Each is intended to sum a series of noise while weighting the sound pressure level for frequency and then adding appropriate nighttime weightings. The older ratings, CNR and NEF, are expressed in terms of maximum Perceived Noise Level and Effective Perceived Noise Level, respectively; each considers a day-night period identical to L_{dn}.

The measure CNEL itself is essentially the same as L_{dn} except for the method of treating nighttime noises. In CNEL, the 24-hour period is broken into three periods: day (0700-1900), evening (1900-2200), and night (2200-0700). Weightings of 5 dB are applied to the evening period and 10 dB to the night period. For most time distributions of aircraft noise around airports, the numerical difference between a two-period and three-period day are not significant, being of the order of several tenths of a decibel at most.

One additional difference between these four similar measures is the method of applying the nighttime weighting and the magnitude of the weighting. The original CNR concept, carried forward in the NEF, weighted the nighttime exposure by 10 dB. Because of the difference in total duration of the day and night periods, 15 and 9 hours respectively, a specific noise level at night receives a weighting of $10 + 10 \log (\frac{15}{9})$, or approximately 12 dB in a reckoning of total exposure. Given the choice of weighting either exposure or level, it is simpler to weight level directly, particularly when actual noise monitoring is eventually considered.

The following paragraphs describe the method utilized to calculate CNR, NEF, and CNEL, as applied principally to aircraft sounds, together with the analogous method for calculating L_{dn}:

Composite Noise Rating Method (CNR)

The original method for evaluating land use around civil airports is the composite noise rating (CNR). It is still in wide use by the Federal Aviation Administration and the Department of Defense for evaluating land use around airfields (Civil Engineering Planning and Programming, "Land Use Planning with Respect to Aircraft Noise," AFM 86-5, TM 5-365, NAVDOCKS P-98, October 1, 1964). This noise exposure scale may be expressed as follows:

The single event noise level is expressed (without a duration or tone correction) as simply the maximum perceived noise level (PNL_{max}) in PNdB.

The noise exposure in a community is specified in terms of the composite noise rating (CNR), which can be expressed approximately as follows:

$$CNR = \overline{PNL}_{max} + 10 \log N_f - 12 \qquad \text{(Eq. A-16)}$$

where

$\overline{PNL}$ = approximate energy mean maximum perceived noise level (PNL) at a given point

N_f = $(N_d + 16.7\ N_n)$, where N_d and N_f the numbers of daytime and nighttime events, respectively.

The constant (-12) is an arbitrary constant, and the factor 16.7 is used to weight the nighttime exposure in the 9-hour night period on a 10 to 1 basis with the daytime exposure in the 15-hour daytime period.

Noise Exposure Forecast (NEF)

This method, currently in wide use, for making noise exposure forecasts utilizes a perceived noise level scale with additional corrections for the presence of pure tones. Two time periods are used to weight the number of flights (Galloway, W.J. and Bishop, D.E., "Noise Exposure Forecasts: Evolution, Evaluation, Extensions and Land Use Interpretations," FAA-N0-70-9, August 1970).

The single event noise level is defined in terms of effective perceived noise level (EPNL) which can be specified approximately by:

$$\mathrm{EPNL} = \mathrm{PNL}_{max} + \log \frac{\Delta t_{10}}{20} + F, (\mathrm{EPNdB}) \qquad \text{(Eq. A-17)}$$

where

PNL_{max} = maximum perceived noise level during flyover, in PNdB,

Δt_{10} = "10 dB down" duration of the perceived noise level time history, in seconds,

and

F = pure tone correction. Typically, F = 0 to + 3 dB

Community noise exposure is then specified by the Noise Exposure Forecast (NEF). For a given runway and one or two dominant aircraft types, the total NEF for both daytime and nighttime operations can be expressed approximately as:

$$\mathrm{NEF} = \overline{\mathrm{EPNL}} + 10 \log N_f - 88.0 \qquad \text{(Eq. A-18)}$$

where

$\overline{\mathrm{EPNL}}$ = energy mean value of EPNL for each single event at the point in question

N_f = same as defined for CNR.

Community Noise Equivalent Level (CNEL)

The following simplified expressions are derived from the exact definitions in the report, "Supporting Information for the Adopted Noise Regulations for California Airports." They can be used to estimate values of CNEL where one type of aircraft and one flight path dominate the noise exposure level.

Single event noise is specified by the single event noise exposure level (SENEL) in dB and can be closely approximated by:

$$\text{SENEL} = NL_{max} + 10 \log_{10} \tau/2 \qquad \text{(dB)} \qquad \text{(Eq. A-19)}$$

where

NL_{max} = maximum noise level as observed on the A scale of a standard sound level meter

and

τ = duration measured between the points of $(L_{max} - 10)$ in seconds. The effective duration is equal to the "energy" of the integrated noise level (NL), divided by the maximum noise level, NL_{max}, when both are expressed in terms of antilogs. It is approximately 1/2 of the 10 dB down duration.

A measure of the average integrated noise level over one hour is also utilized in the proposed standard. This is the hourly noise level (in dB), defined as:

$$\text{HNL} = \overline{\text{SENEL}} + 10 \log n - 35.6 \qquad \text{(dB)} \qquad \text{(Eq. A-20)}$$

where

SENEL = energy mean value of SENEL for each single event,

and

n = number of flights per hour

The total noise exposure for a day is specified by the community noise equivalent level (CNEL) in dB, and may be expressed as:

$$\text{CNEL} = \overline{\text{SENEL}} + 10 \log N_c - 49.4 \qquad \text{(dB)} \qquad \text{(Eq. A-21)}$$

where

$N_c = (N_d + 3N_e + 10N_n)$

or

$= (12\bar{n}_d + 9\bar{n}_e + 90\bar{n}_n)$

$N_d, \bar{n}_d$ = total number and average number per hour, respectively, of flights during the period 0700 to 1900

$N_e, \bar{n}_e$ = total number and average number per hour, respectively, of flights during the period 1900 to 2200

and

$N_n, \bar{n}_n$ = total number and average number per hour, respectively, of flights during the period 2200 to 0700

Day-Night Sound Level (L_{dn})

The following simplified expressions are useful for estimating the value of L_{dn} for a series of single event noises which are of sufficient magnitude relative to the background noise that they control L_{dn}:

Single event noise is specified by the sound exposure level (L_{ex}) measured during a single event. It can be closely approximated by:

$$L_{ex} \cong L_{max} + 10 \log_{10} \tau/2 \quad \text{(dB)} \qquad \text{(Eq. A-22)}$$

where

L_{max} = maximum sound level as observed on the A scale of a standard sound level meter on the slow time characteristic

and

τ = duration measured between the points of (L_{max} - 10) in seconds

The day-night sound level may be estimated by:

$$L_{dn} = \overline{L_{ex}} + 10 \log N - 49.4 \quad \text{(dB)} \qquad \text{(Eq. A-23)}$$

where

$\overline{L_{ex}}$ = the energy mean value of the single event L_{ex} values

$N = (N_d + 10N_n)$

or

N_d = total number of events during the period 0700 to 2200

and

N_n = total number of events during the period 2200 to 0700

There is no fixed relationship between L_{dn} or CNEL and CNR or NEF because of the differences between the A-level and PNL frequency weightings and the allowance for duration, as well as the minor differences in approach to day-night considerations. Nevertheless, one may translate from one measure to another by the following approximate relationship:

$$L_{dn} \doteq \text{CNEL} \doteq \text{NEF} + 35 \doteq \text{CNR} - 35 \qquad \text{(Eq. A-24)}$$

For most circumstances involving aircraft flyover noise, these relationships are valid within about a ± 3 dB tolerance.

Comparison of L_{eq} with HUD Guideline Interim Standards (1390.2 Chg. 1)

The interim HUD standards for outdoor noise are specified for all noise sources, other than aircraft, in terms of A-weighted sound level not to be exceeded more than a certain fraction of the day. Aircraft noise criteria are stated in terms of NEF or CNR.

The HUD exposure criteria for residences near airports are "normally acceptable" if NEF 30 or CNR 100 is not exceeded. A "discretionary acceptable" category permits exposures up to NEF 40 or CNR 115.

For all other noise sources, the HUD criteria specify a series of acceptable, discretionary, and unacceptable exposures. Since these specifications are similar to points on a cumulative statistical description of noise levels, it is of interest to compare the HUD criteria with L_{eq} for different situations. For discussion purposes, consider the boundary between the categories "discretionary-normally acceptable" and "unacceptable."

The first criterion defining this boundary allows A-weighted noise levels to exceed 65 dB up to 8 hours per 24 hours, while the second criterion states that noise levels exceeding 80 dB should not exceed 60 minutes per 24 hours. These two values may be used to specify two limit points on a cumulative distribution function, $L_{33.3}$ = 65 dB and $L_{4.2}$ = 80 dB. The relationship between L_{eq} and the HUD criteria may then be examined for different types of distribution functions, restricting the shape of the distribution only so that it does not exceed these two limit points.

First consider two cases of a normal distribution of noise levels, comparable to vehicle traffic noise. For the first case, assume a distribution with quite narrow variance so placed on the graph that the 65 dB point is not exceeded (see Figure A-8). For this curve, to the nearest decibel, L_{50} = 64 dB, and the corresponding standard deviation (arbitrarily chosen small) is 2.3 dB. The resulting L_{eq} is equal to 64.6 dB.

Now consider a normal distribution with the widest permissible variance (the curve marked Maximum Variance in Figure A-8); if the variance were any greater, the distribution would violate HUD's requirement that the level not exceed 80 dB for more than 60 minutes per 24 hours. This distribution, to the nearest decibel, has L_{50} = 60 dB, L_{10} = 74 dB and a standard deviation of approximately 11 dB. The resultant L_{eq} = 74 dB, is almost 10 dB higher than for the previous case. Both curves meet HUD's interim standards.

Next, consider a series of intermittent high level noises, superposed on a typical urban/suburban background noise level, such that 80 dB is not exceeded more than 60 minutes per 24 hours, say 4%. Choosing a series of repeated triangular-shaped time signals of 90 dB maximum sound level will produce an L_{eq} value of 72.4 dB without exceeding an L_4 value of 80 dB.

However, one can allow the maximum level to increase indefinitely provided L_4 remains at 80 dB or less. The limiting case is that of a square-shaped time pattern, switched on and off. In this instance, if the total "on-time" is 4% or less, the value of L_{eq} is equal to L_{max} - 14 dB, and both L_{max} and L_{eq} can increase without limit and still remain acceptable within the HUD interim standards. Maximum A-levels for an aircraft can be as high as 110 dB, which would permit L_{eq} values of 96 to be obtained without exceeding the L_4 limit of 80 dB.

It is clear that no unique relationship can be specified between the HUD non-airport standards and L_{eq}. Values of L_{eq} ranging up to 95 dB can be found in compliance with the HUD outdoor noise standard depending on the time distribution of noise levels considered. Even if the nighttime penalty were applied to L_{eq} to yield L_{dn} there would still be no unique relation with the HUD standards.

Comparison of L_{eq} With Federal Highway Administration Noise Standards, PPM 90-2, February 8, 1973

The primary criteria of PPM 90-2 are that L_{10} for noise levels inside people-occupied spaces shall not exceed 55 dB, or for sensitive outdoor spaces "–in which serenity and quiet are of extraordinary significance–," 60 dB.

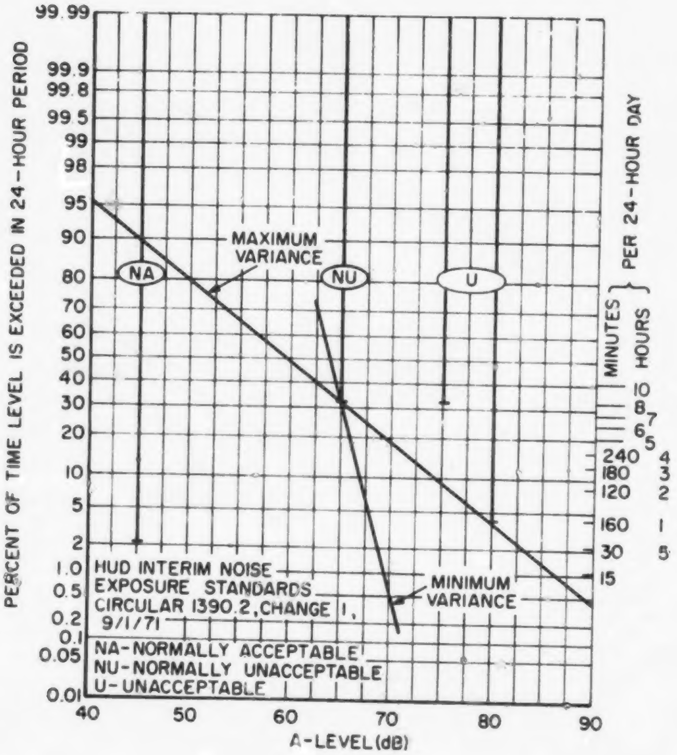

Figure A-8. Permissible Normal Distributions of L_{eq} Under HUD Standards^{A-25}

Highway noise often has a random distribution of noise level, the distribution function being approximately normal in many instances. In this case, the relationship between L_{eq} and L_{10} is given by the expression:

$$L_{eq} = L_{10} - 1.28\,s + 0.115\,s^2 \qquad \text{(dB)} \qquad \text{(Eq. A-25)}$$

where s is the standard deviation of the noise level distribution. The difference between L_{10} and L_{eq} for normal distribution of sound level is plotted in Figure A-6. It can be noted that $L_{eq} = L_{10} - 2$ dB within ±2 dB, for s ranging from 0 to 11 dB. Highway noise rarely has a standard deviation of 11 dB; 2 to 5 dB is more typical.

Thus, setting L_{10} at 60 dB for highway noise impacting a sensitive outdoor space, we find that an L_{eq} value of 60 -2 = 58 ±2 dB would meet the most sensitive FHWA criterion.

REFERENCES FOR APPENDIX A

A-1. "Report to the President and Congress on Noise," Environmental Protection Agency, NRC 500.1, December 31, 1971.

A-2. Bishop, D.E., "Judgements of the Relative and Absolute Acceptability of Aircraft Noise," *J. Acoust. Soc. Am. 40*:103, December 1966.

A-3. Kryter, K.D., "The Effects of Noise on Man," Academic Press, New York, 1970.

A-4. "House Noise - Reduction Measurements for Use in Studies of Aircraft Flyover Noise," Society of Automotive Engineers, Inc., AIR 1081, October 1971.

A-5. Bishop, D.E., and Horonjeff, R.O., "Procedures for Developing Noise Exposure Forecast Areas for Aircraft Flight Operations," FAA Report DS-67-10, August 1967.

A-6. Stevens, K.N., and Pietrasanta, A.C., and the Staff of Bolt Beranek and Newman, Inc., "Procedures for Estimating Noise Exposure and Resulting Community Reactions from Air Base Operations," WADC Technical Note 57-10, Wright-Patterson Air Force Base, Ohio, Wright Air Development Center, 1957.

A-7. Eldred, K.M., Gannon, W.J., and von Gierke, H.E., "Criteria for Short Time Exposure of Personnel to High Intensity Job Aircraft Noise," WADC Technical Note 55-355, Wright-Patterson Air Force Base, Ohio, 1955.

A-8. Air Force Regulation 160-3, "Hazardous Noise Exposure," USAF, October 29, 1956.

A-9. Burck, W., Grutzmacher, M., Meister, F.J., Muller, E.A., and Matschat, K., "Fluglarm, Gutachten erstattet im Auftrag des Bundesministers fur Gesundheitswesen," (Aircraft Noise: Expert Recommendations Submitted under Commission from the German Federal Ministry for Public Health), Gottingen, 1965.

A-10. Bruckmayer, F. and Lang, J., "Storung der Bevolkerung durch Verkehrslarm" (Disturbance of the Population by Traffic Noise), Oesterreiche Ingenieur-Zeitschrift, Jg. 1967, H.8, 302-306; H.9, 338-344; and H.10, 376-385.

A-11. Bruckmayer, F., and Lang, J., "Storung durch Verkehrslarm in Unterrichtstraume" (Disturbance Due to Traffic Noise in Schoolrooms), Oesterreichische Ingenieur-Zeitschrift, *11* (3): 73-77, 1968.

A-12. "Schallschutz: Begriffe" (Noise Control: Definitions), TGL 10 687, Blatt 1 (Draft), Deutsche Bauinformation, East Berlin, November 1970.

A-13. "Mittelung zeitlich schwankender Schallpegel (Aquivalenter Dauerschallpegal)" (Evaluation of Fluctuating Sound Levels (The Equivalent Continuous Sound Level)), DIN 54 641, (Draft), Deutsche Normen, Beuth-Vertrieb GmbH, Berlin 30, April 1971.

A-14. "Schallschutz: Territoriale und Stadtebauliche Planung" (Noise Control: Land Use and City Planning), TGL 10 687, Blatt 6, (Draft), Deutsche Bauinformation, East Berlin, November 1970.

A-15. "Schallschutz in Stadtebau" (Noise Control in City Planning), DIN 18 005, (Draft), Deutsche Normen, Beuth-Vertrieb GmbH, Berlin 30, August 1968.

A-16. Benjegard, Sven-Olaf, "Bullerdosimetern" (The Noise Dose Meter), Report 51/69, Statens institut fur byggnadsforskning, Stockholm, 1969.

A-17. Robinson, D.W., and Cook, J.P., NPL Aero Report No. Ac 31, National Physical Laboratory, England, June 1968.

A-18. Meister, F.J., "Der Einfluss der Einwirkdauer bei der Beschallung des Ohres" (The Influence of the Effective Duration in Acoustic Excitation of the Ear), Larmbekampfung 10 (3/4), June/August 1966.

A-19. Pearsons, K.S., "The Effects of Duration and Background Noise Level on Perceived Noisiness," FAA ADS-78, April 1966.

A-20. Galloway, W.J., and Bishop, D.E., "Noise Exposure Forecasts: Evolution, Evaluation, Extensions and Land Use Interpretations," Bolt Beranek and Newman, Inc., Report No. 1862, August 1970; also FAA-No-70-9.

A-21. "Procedure for Describing Noise Around an Airport," R-507, International Standards Organization, Geneva, 1970.

A-22. "Noise Assessment with Respect to Community Noise," R-1996, International Standards Organization, Geneva, 1970.

A-23. "Assessment of Noise-Exposure During Work for Hearing Conservation," R-1999, International Standards Organization, Geneva, 1970.

A-24. Galloway, W.J., "Review of Land Use Planning Procedures," Interim Technical Report, Aerospace Medical Research Laboratory, WPAFB, Ohio, March 1972.

A-25. "Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure," Environmental Protection Agency, NTID 73.4, 1973.

APPENDIX B

LEVELS OF ENVIRONMENTAL NOISE IN THE U.S. AND TYPICAL EXPOSURE PATTERNS OF INDIVIDUALS

APPENDIX B

LEVELS OF ENVIRONMENTAL NOISE IN THE U.S. AND TYPICAL EXPOSURE PATTERNS OF INDIVIDUALS

Levels of environmental noise for various defined areas are provided for both the outdoor and indoor situations. Examples are then used to illustrate how an individual's daily dose accumulates from the exposure to such noise levels.

LEVELS OF ENVIRONMENTAL NOISE

Outdoor Sound Levels

The range of day-night sound levels (L_{dn}) in the United States is very large, extending from the region of 20-30 dB estimated for a quiet* wilderness area to the region of 80-90 dB in the most noisy urban areas, and to still higher values within the property boundaries of some governmental, industrial and commercial areas which are not accessible to the general public. The measured range of values of day-night sound levels outside dwelling units extends from 44 dB on a farm to 88.8 dB outside an apartment located adjacent to a freeway. Some examples of these data are summarized in Figure B-1.

The dominant sources for outdoor noise in urban residential areas are motor vehicles, aircraft and voices. This conclusion has been found in several studies, including a recent survey [B-1] of 1200 people which is summarized in Table B-1.

The cumulative number of people estimated to reside in areas where the day-night sound level exceeds various values is given in Table B-2. In the areas where the L_{dn} exceeds 60 dB, the proportion between the number of people residing in areas where the outdoor noise environment is dominated by aircraft and those residing in areas where motor vehicles dominate is approximately one to four. This proportion is almost identical to the proportion found in the survey, previously summarized in Table B-1 where people were asked to judge the principle contributing sources of neighborhood noise. The estimates in Table B-2 of the

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*Measurement approximately 25 feet from a mountain waterfall on a small canyon stream in Wyoming gave an L_{dn} of approximately 85 dB.[B-2]

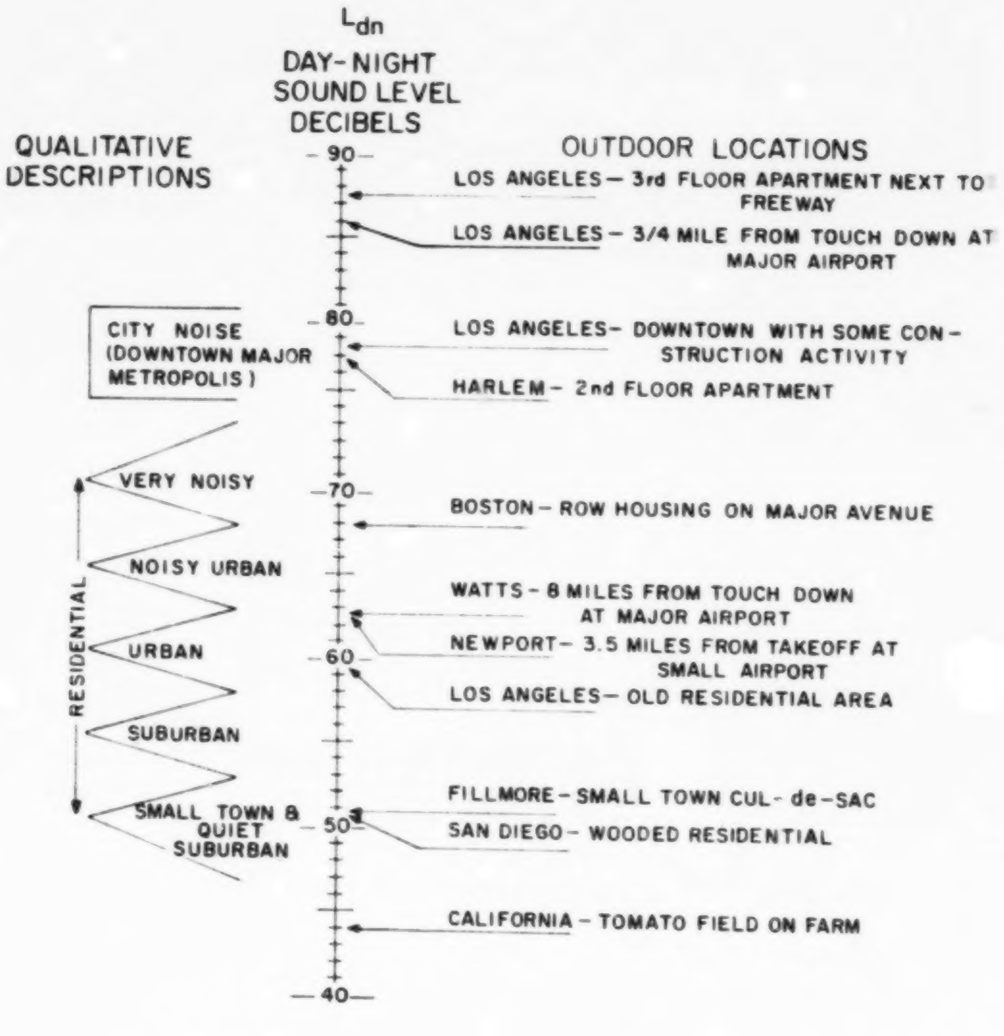


Figure B-1. Examples of Outdoor Day-Night Sound Level in dB (re 20 micropascals) Measured at Various Locations[B-4]

Table B-1

PERCENT CONTRIBUTION OF EACH SOURCE IDENTIFIED BY RESPONDENTS CLASSIFYING THEIR NEIGHBORHOOD AS NOISY (72% OF 1200 RESPONDENTS)[B-3]

Source	Percentage
Motor Vehicles	55
Aircraft	15
Voices	12
Radio and TV Sets	2
Home Maintenance Equipment	2
Construction	1
Industrial	1
Other Noises	6
Not Ascertained	8

Table B-2

ESTIMATED CUMULATIVE NUMBER OF PEOPLE IN MILLIONS IN THE UNITED STATES RESIDING IN URBAN AREAS WHICH ARE EXPOSED TO VARIOUS LEVELS OF OUTDOOR DAY/NIGHT AVERAGE SOUND LEVEL,[B-4,B-5]

Outdoor L_{dn} Exceeds	Urban Traffic	Freeway Traffic	Aircraft Operations	Total
60	59.0	3.1	16.0	78.1
65	24.3	2.5	7.5	34.3
70	6.9	1.9	3.4	12.2
75	1.3	0.9	1.5	3.7
80	0.1	0.3	0.2	0.6

number of people living in areas which are exposed to freeway and aircraft noise are taken from the EPA airport/aircraft noise report.[B-4] They were based on calculated noise contours and associated populations for a few selected situations which formed the basis for extrapolation to national values. The estimates for the number of people living in areas in which the noise environment is dominated by urban traffic were developed from a survey[B-5] conducted in Summer 1973 for EPA. The survey measured the outdoor 24-hour noise environment at 100 sites located in 14 cities, including at least one city in each of the ten EPA regions. These data, supplemented with that from previous measurements at 30 additional sites, were correlated with census tract population density to obtain a general relationship between L_{dn} and population density. This relationship was then utilized, together with census data giving population in urban areas as a function of population density, to derive the national estimate given in Table B-2.

These data on urban noise enable an estimate of the percentage urban population in terms of both noise levels and the qualitative descriptions of urban residential areas which were utilized in the Title IV EPA report to Congress in 1971.[B-6]

These estimates, summarized in Table B-3, show that the majority of the 134 million people residing in urban areas have outdoor L_{dn} values ranging from 43 dB to 72 dB with a median value of 59 dB. The majority of the remainder of the population residing in rural or other non-urban areas is estimated to have outdoor L_{dn} values ranging between 35 and 50 dB.

Indoor Sound Levels

The majority of the existing data regarding levels of environmental noise in residential areas has been obtained outdoors. Such data are useful in characterizing the neighborhood noise environment evaluating the noise of identifiable sources and relating the measured values with those calculated for planning purposes. For these purposes, the outdoor noise levels have proved more useful than indoor noise levels because the indoor noise levels contain the additional variability of individual building sound level reduction. This variability among dwelling units results from type of construction, interior furnishings, orientation of rooms relative to the noise, and the manner in which the dwelling unit is ventilated.

Data on the reduction of aircraft noise afforded by a range of residential structures are available.[B-7] These data indicate that houses can be approximately categorized into "warm climate" and "cold climate" types. Additionally, data are available for typical open-window and closed-window conditions. These data indicate that the sound level reduction provided by buildings within a given community has a wide range due to differences in the use of materials, building techniques, and individual building plans. Nevertheless, for

Table B-3
ESTIMATED PERCENTAGE OF URBAN POPULATION (134 MILLION) RESIDING IN AREAS WITH VARIOUS DAY-NIGHT NOISE LEVELS TOGETHER WITH CUSTOMARY QUALITATIVE DESCRIPTION OF THE AREA[B-3,B-4]

Description	Typical Range L_{dn} in dB	Average L_{dn} in dB	Estimated Percentage of Urban Population	Average Census Tract Population Density, Number of People Per Square Mile
Quiet Suburban Residential	48-52	50	12	630
Normal Suburban Residential	53-57	55	21	2,000
Urban Residential	58-62	60	28	6,300
Noisy Urban Residential	63-67	65	19	20,000
Very Noisy Urban Residential	68-72	70	7	63,000

planning purposes, the typical reduction in sound level from outside to inside a house can be summarized as follows in Table B-4. The approximate national average "window open" condition corresponds to an opening of 2 square feet and a room absorption of 300 sabins (typical average of bedrooms and living rooms). This window open condition has been assumed throughout this report in estimating conservative values of the sound levels inside dwelling units which results from outdoor noise.

The sound levels inside dwelling units result from the noise from the outside environment plus the noise generated internally. The internally generated noise results from people activity, appliances and heating and ventilating equipment. Twenty-four hour continuous measurements were made in 12 living rooms (living, family or dining room) in 12 houses during the 100-site EPA survey[B-5] of urban noise, excluding areas where the noise resulted from freeways and aircraft. The results, summarized below in Table B-5, show that the inside day-night sound level in these homes was the result of internally generated noise. In fact, the internal L_{dn} and L_d values were slightly higher than those measured outdoors, despite the fact that the average house sound level reduction appeared to exceed 18 dB. The pattern for the indoor sound levels varies significantly among the homes, as portrayed by the data in Figure B-2. The hourly equivalent sound levels have an average minimum of approximately

Table B-4

SOUND LEVEL REDUCTION DUE TO HOUSES* IN WARM AND COLD CLIMATES, WITH WINDOWS OPEN AND CLOSED[B-7]

	Windows *Open*	Windows *Closed*
Warm climate	12 dB	24 dB
Cold climate	17 dB	27 dB
Approximate national average	15 dB	25 dB

*(Attenuation of outdoor noise by exterior shell of the house)

Table B-5

COMPARISON OF INTERNAL AND OUTDOOR SOUND LEVELS IN LIVING AREAS AT 12 HOMES[B-7]

	Daytime Sound Level (L_d) in dB	Nighttime Sound Level (L_n) in dB	Day-Night Sound Level L_{dn} in dB
Outdoors:			
Average	57.7	49.8	58.8
Standard Deviation	3.1	4.6	3.6
Indoors:			
Average	59.4	46.9	60.4
Standard Deviation	5.6	8.7	5.9
Difference:			
Outdoors Minus Indoors	1.7	2.9	-1.6

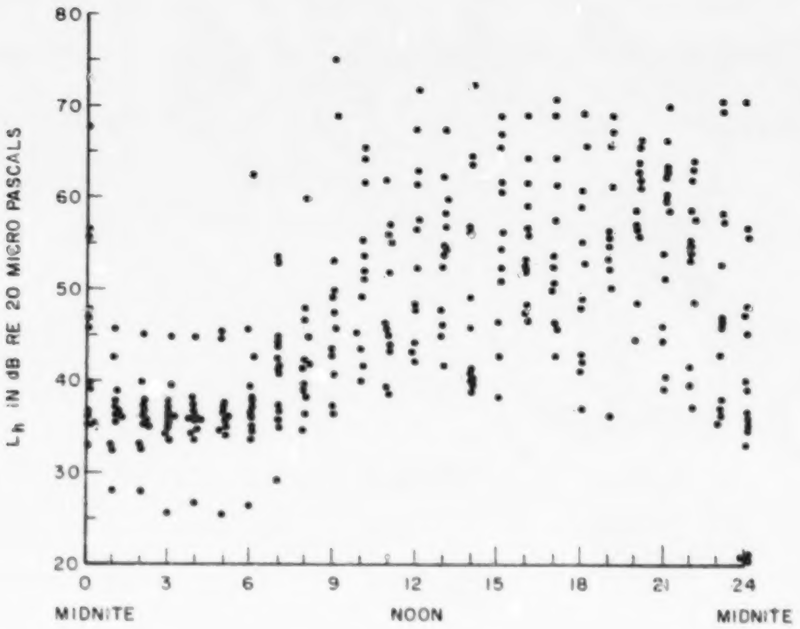


Figure B-2. Noise Inside Living Areas of 12 Homes - Values of Hourly Equivalent Sound Level as a Function of Hour of Day[B-5]

36 dB during the hours between 1 a.m. and 6 a.m. This minimum level is probably governed by outdoor noise in the majority of the situations. However, when people are active in the daytime, the hourly equivalent sound levels have a range of over 30 dB, depending on the type of activity. Thus, during the waking hours, the outdoor noise sets a lower bound of indoor noise. For the outdoor L_{dn} range of 52-65 dB this lower bound is significantly below the average level of the internally generated noise.

EXAMPLES OF INDIVIDUAL NOISE EXPOSURES

The noise exposures received by individuals are very much a function of the individual's life style. The variation in these exposures can be illustrated by examining several typical daily activity patterns. While these patterns are realistic, they should not be construed as applying to all individuals following the particular life style depicted.

The total daily exposure, $L_{eq(24)}$ is considered the sum of the sound energy from all daily exposure, including occupational exposures. Mathematically this can be interpreted as:

$$L_{eq}(24\text{ hr}) = 10 \log \left[\sum_{i=1}^{n} t_i \times 10^{L(t_i)/10} \right] -49.4$$

where: $L(t_i)$ is the L_{eq} value for the appropriate time periods, (t_i) and the summation of all the t_i's must equal a total of 24 hours (i.e., $\sum_{i=1}^{n} t_i = 24$ hours (86400 sec.)).

Five different exposure patterns for a 24-hour day are depicted in Figures B-3 to B-7. The patterns are representative of the exposures that might be incurred by:

Factory worker - Figure B-3
Office worker - Figure B-4
Housewife - Figure B-5
School child - Figure B-6
Pre-school child - Figure B-7

Certain assumptions were made in determining the levels shown in Figure B-3 to B-7. First, it was assumed that the suburban environment was equal to an L_{dn} of 50 ($L_d = 50$, $L_n = 40$). For the urban environment, the L_{dn} value was 75 ($L_d = 72$, $L_n = 68$). The levels for the various activities were determined from previous EPA reports on appliance noise, transportation noise, as well as information contained in the EPA Task Group No. 3 Report relating to aircraft noise.[B-4]

Values for the Equivalent Sound level ($L_{eq(24)}$) experienced by the individual are computed from the basic formulation of L_{eq}. For each of these lifestyles, the $L_{eq(24)}$ value and the L_{dn} values are equivalent as the controlling noise dose normally does not occur at night. This emphasizes that for most practical situations, the average individual L_{dn} dose or $L_{eq(24)}$ individual dose are interchangeable.

Noise levels for other lifestyles could also be generated. However, it is important to remember that $L_{eq(24)}$ values are, in most cases, controlled by the 2- to 3-hour exposures to relatively high level noise. For example, assume a motorcycle rider rode his vehicle for 2 hours a day at an exposure of 100 dB producing an $L_{eq(24)}$ of 89; if this were the case, then other noise producing activities during the day would have little effect on the L_{dn} if they were at a level of at least 15 dB below the level of the motorcycle.

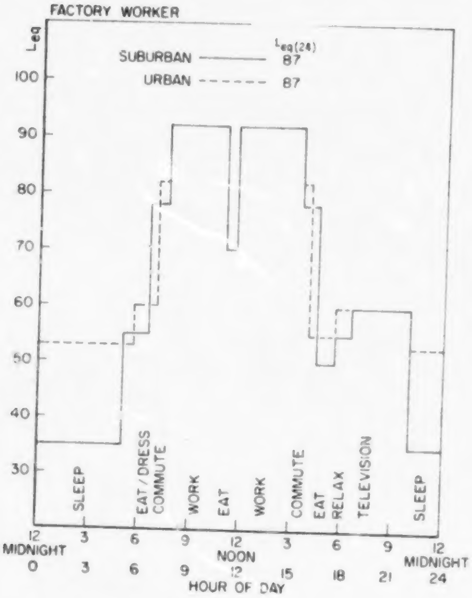


Figure B-3. Typical Noise Exposure Pattern of a Factory Worker[B-1,B-4,B-8,B-9]

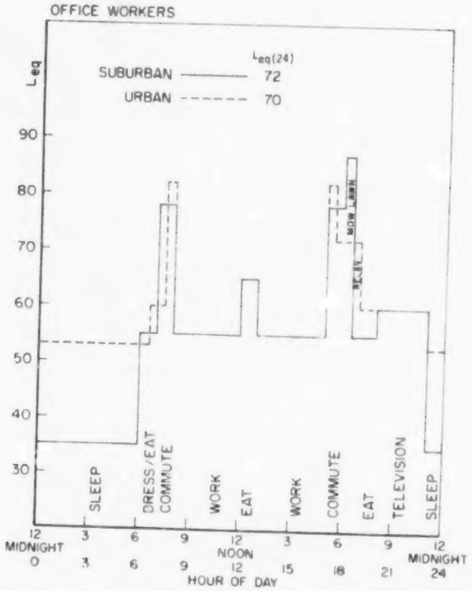


Figure B-4. Typical Noise Exposure Pattern of an Office Worker[B-1,B-4,B-8,B-9]

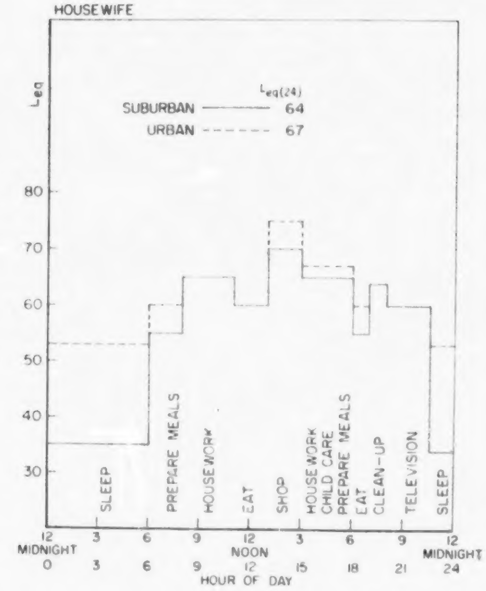


Figure B-5. Typical Noise Exposure Pattern of a Housewife[B-1,B-4,B-8,B-9]

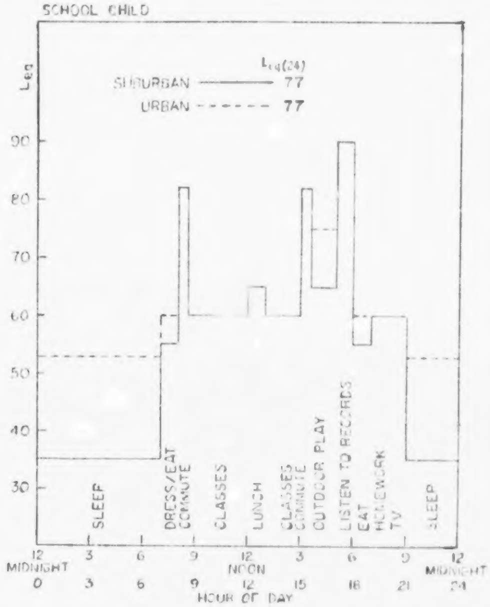


Figure B-6. Typical Noise Exposure Pattern of a School Child[B-1,B-4,B-8,B-9]

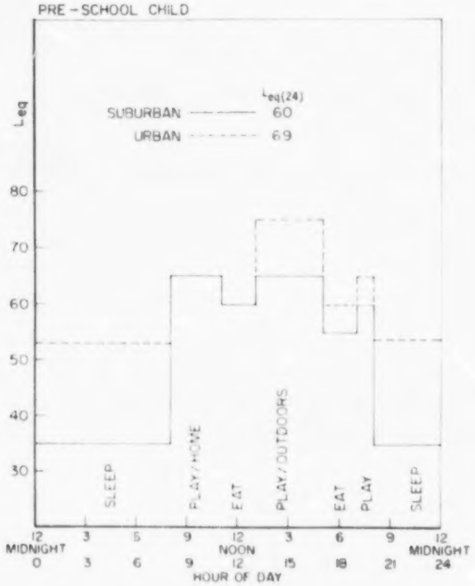


Figure B-7. Typical Noise Exposure Pattern of a Pre-School Child
B-1, B-4, B-8, B-9

REFERENCES FOR APPENDIX B

B-1. Eldred, K.M., "Community Noise," Environmental Protection Agency NTID 300.3, December 1971.

B-2. Garland, W.L., Hanna, S.J. and Lamb, D.R., "Ambient Noise, Wind and Air Attentuation in Wyoming," Proceedings of Noise-Con 73, Washington, D.C., October 1973.

B-3. Bolt Beranek and Newman, Inc., "Survey of Annoyance from Motor Vehicle Noise," Automobile Manufacturers Association, Inc., Report 2112, June 1971.

B-4. "Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure," Environmental Protection Agency NTID 73.4, July 27, 1973.

B-5. Galloway, D. and Eldred, K., 100-Site Report, in preparation as a BBN Report for the Environmental Protection Agency.

B-6. "Report to the President and Congress on Noise," Environmental Protection Agency NRC 500.1, December 31, 1971.

B-7. "House Noise - Reduction Measurements for Use in Studies of Aircraft Flyover Noise," Society of Automotive Engineers, Inc., AIR 1081, October 1971.

B-8. "Transportation Noise and Noise from Equipment Powered by Internal Combustion Engines," Environmental Protection Agency NTID 300.13, December 1971.

B-9. "Noise from Construction Equipment and Operations, Building Equipment and Home Appliances," Environmental Protection Agency NTID 300.1, December 1971.

APPENDIX C

NOISE-INDUCED HEARING LOSS

APPENDIX C

NOISE-INDUCED HEARING LOSS

INTRODUCTION

A considerable amount of hearing loss data have been collected and analyzed. These data include measurements of hearing loss in people with known histories of noise exposure. Much of the analysis consists of grouping these measurements into populations of the same age with the same history of noise exposure and determining the percentile distribution of hearing loss for populations with the same noise exposure. Thus, the evidence for noise-induced permanent threshold shift can be clearly seen by comparing the distribution of a noise-exposed population with that of a relatively non-noise-exposed population.

Most of these data are drawn from cross-sectional research rather than longitudinal studies. That is, individuals or populations have been tested at only one point in time. Because complete noise-exposure histories do not exist, many conclusions are limited by the need to make certain hypotheses about the onset and progression of noise-induced hearing loss. Different hypotheses about the time history will lead to different conclusions even from the same data base, although the range of such conclusions is limited. Thus, in reaching conclusions about hearing loss, reliance is made on assumptions, hypotheses, and extrapolations which are not all universally accepted by the scientific community. However, attempts have been made to consider differing opinions and to insure that the methodology and conclusions in this section are in the mainstream of current scientific thought.

BASIC ASSUMPTIONS AND CONSIDERATIONS

In order to proceed further, it is necessary to make the following well-based assumptions:

1. Hearing shifts in the "non-noise-exposed" populations are attributable to aging and other causes rather than to noise exposure.

2. As individuals approach the high end of the distribution and their hearing becomes worse, they become less affected by noise exposure. In other words, there comes a point where one cannot be damaged by sounds that one cannot hear.

In addition, there are some important considerations necessary for the identification of a level to protect against hearing loss.

Preservation of High Frequency Hearing

The levels identified in this document for hearing conservation purposes are those which have been shown to provide protection from any measurable degradation of hearing acuity. This protection is provided even for those portions of the hearing mechanism which respond to the audiometric frequency at which noise-induced hearing impairment first occurs, namely 4000 Hz. The definition of hearing handicap originated by the American Academy of Opthalmology and Otolaryngology (AAOO), and currently incorporated in many hearing damage-risk criteria, is somewhat different from the definition used in this document. Hearing handicap, (and later, hearing impairment) was defined by a formula which used the average hearing level at 500 Hz, 1000 Hz and 2000 Hz.

Although hearing loss for frequencies above 2000 Hz is not treated as significant by most of the existing occupational hearing damage-risk criteria, the ability to hear frequencies above 2000 Hz is important for understanding speech and other signals. Despite the traditional use of the term "speech frequencies" to apply to 500, 1000 and 2000 Hz, useful energy in speech sound ranges from about 200 to 6100 Hz.[C-1] It has been known for many years that the equal discriminability point in the speech spectrum is at about 1600 Hz. That is, frequencies above 1600 Hz are equal in importance to those below 1600 Hz for understanding speech.[C-1] However, there are other reasons for preserving the frequencies above 2000 Hz. Higher frequencies are important for the localization and identification of faint, high-pitched sounds in a variety of occupational and social situations. Detection of soft, relatively high-frequency sounds can be especially important in vigilance tasks, such as those which may occur in the military. In addition, good hearing for the higher frequencies is important to hear everyday occurrences such as sounds indicative of deterioration in mechanical equipment, crickets on a summer evening, bird song, and certain musical sounds. In fact, high-fidelity sound reproducing equipment is often promoted on the basis of its fidelity up to 15,000 Hz, or even 30,000 Hz.

Any measurable hearing loss at any frequency is unacceptable if the goal is protection of health and welfare with an adequate margin of safety. For most environmental noise, protection at 4000 Hz will insure that all other frequencies are protected.[C-2] Thus, the 4000 Hz frequency has been selected as the most sensitive indicator of the auditory effects of environmental noise.

Significant Changes in Hearing

In this section an attempt will be made to determine the relation between exposure level and noise-induced permanent threshold shift (NIPTS). Before this is accomplished, however, the significance of various amounts of NIPTS needs to be addressed.

For the purposes of identifying the levels in this document, it was necessary to adopt a criterion for an allowable amount of NIPTS. Whereas a NIPTS of 0 dB would be ideal, it is not appropriate for the following reasons:

1. Most audiometric equipment does not have the capability to measure hearing levels in less than 5 dB steps.

2. There is no known evidence that NIPTS of less than 5 dB are perceptible or have any practical significance for the individual.

3. Individual hearing thresholds are subject to minor fluctuations due to transitory psychological or physiological phenomena.

NIPTS of considerably larger amounts have been permitted in various damage-risk criteria in the past. For instance, shifts of 10 dB to 20 dB have been considered reasonable.[C-3] However, the requirement for an adequate margin of safety necessitates a highly conservative approach. This approach dictates the prevention of any effect on hearing, which is defined here as an essentially insignificant and unmeasurable NIPTS, i.e., a NIPTS of less than 5 dB. The available evidence consists of statistical distributions of hearing levels for populations at various exposure levels. The evidence of NIPTS, then, is the shift in the statistical distribution of hearing levels for a noise-exposed population in comparison to that of a non-exposed population.

PREDICTION OF NOISE-INDUCED PERMANENT THRESHOLD SHIFT

Status of Hearing at 4000 Hz in the United States

Figure C-1 summarizes hearing levels of the general U.S. population at 4000 Hz. The data are from the Public Health Survey (PHS) conducted in 1960-62 in the United States.[C-4] Robinson's[C-5] non-noise-exposed and otologically screened population is shown for comparison. Several points should be noted.

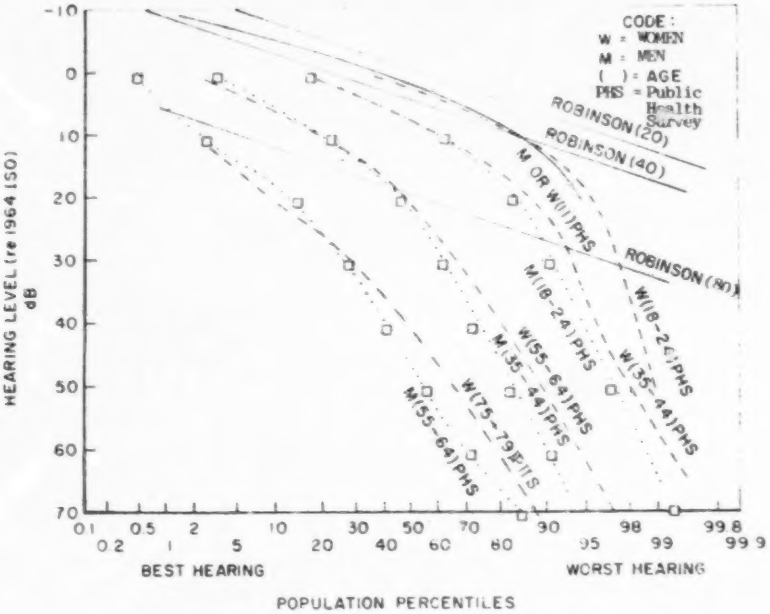


Figure C-1. Population Hearing Levels at 4000 Hz[C-4,C-5,C-6]

1. The hearing of a selected percentile of the population can be determined for various age groups. As displayed here, the higher the percentile point, the worse the hearing.

2. At age 11, there is no hearing difference due to sex,[C-6] but for the 18-24 age group, a definite difference is evident, with men's hearing considerably worse.

3. Considering that there is no evidence for any sex-inherent differences in susceptibility to hearing impairment, it is most likely that the differences displayed are due to noise exposure.

The Effect of Noise on Hearing

Table C-1 summarizes the hearing changes expected for daily exposures to various values of steady noise, for an eight-hour day, over 10- and 40-year periods.[C-7]

Four different measurement parameters are considered in Table C-1:

1. Max NIPTS: The permanent change in hearing threshold attributable to noise. NIPTS increases with exposure duration. Max NIPTS is the maximum value during a 40-year

Table C-1
SUMMARY OF THE PERMANENT HEARING DAMAGE EFFECTS
EXPECTED FOR CONTINUOUS NOISE EXPOSURE AT
VARIOUS VALUES OF THE A-WEIGHTED AVERAGE
SOUND LEVEL[C-7]

75 dB for 8 hrs

	av.0.5,1,2 kHz	av.0.5,1,2,4 kHz	4 kHz
Max NIPTS 90th percentile	1 dB	2 dB	6 dB
NIPTS at 10 yrs. 90th percentile	0	1	5
Average NIPTS	0	0	5
Max NIPTS 10th percentile	0	0	0

80 dB for 8 hrs

	av.0.5,1,2 kHz	av.0.5,1,2,4 kHz	4 kHz
Max NIPTS 90th percentile	1 dB	4 dB	11 dB
NIPTS at 10 yrs. 90th percentile	1	3	9
Average NIPTS	0	1	4
Max NIPTS 10th percentile	0	0	2

85 dB for 8 hrs

	av.0.5,1,2 kHz	av.0.5,1,2,4 kHz	4 kHz
Max NIPTS 90th percentile	4 dB	7 dB	19 dB
NIPTS at 10 yrs. 90th percentile	2	6	16
Average NIPTS	1	3	9
Max NIPTS 10th percentile	1	2	5

90 dB for 8 hrs

	av.0.5,1,2 kHz	av.0.5,1,2,4 kHz	4 kHz
Max NIPTS 90th percentile	7 dB	12 dB	28 dB
NIPTS at 10 yrs. 90 percentile	4	9	24
Average NIPTS	3	6	15
Max NIPTS 10th percentile	2	4	11

Example: For an exposure of 85 dB during an 8-hour working day, the following effects are expected:

Table C-1 (continued)

For the 90th percentile point, the Max NIPTS occurring typically during a 40-year work lifetime, averaged over the four frequencies of 0.5, 1, 2 and 4 kHz, is 7 dB; averaged over the three frequencies of 0.5, 1, and 2 kHz is 4 dB and 19 dB at 4 kHz. For this same 90th percentile point of the population, the expected NIPTS after only 10 years of exposure would be 6 dB averaged over the four frequencies, 2 dB averaged over three frequencies, and 15 dB at 4 kHz.

exposure that starts at age 20. Data from the 90th percentile point of the population will be used to extrapolate to higher percentiles.

2. NIPTS at 10 years: The entries on this row also apply to the 90th percentile point of the population for 10 years of exposure.

3. Average NIPTS: The value of NIPTS is averaged over all the percentiles for all age groups. (This figure differs by only a couple of decibels from the median NIPTS after 20 years of exposure for the entire population.)

The values in Table C-1 are arithmetic averages of data found in the reports of Passchier-Vermeer,[C-8] Robinson,[C-5] and Baughn.[C-9]

DERIVATION OF EXPOSURE LEVELS

Selection of the Percentile and Related Exposure Level

The estimation of NIPTS for a given percentile has been accomplished by subtracting the hearing level of that percentile of the non-noise-exposed group from the hearing level of the respective percentile of the noise-exposed group. People above the 90th percentile are those whose hearing is worse than that of 90 percent of the population. Thus, for example, if the group at the 90th percentile shows a shift of 10 dB because of noise exposure, then it is considered that the group has a NIPTS of 10 dB. Extrapolations above the 90th percentile can be made from existing data, as done in Figure C-2. These extrapolations require cautious interpretation. First, the data for the 75 dB exposure levels in Table C-1 are themselves derived from extrapolations. The last firm data are at 78 dB. Second, for many of the studies that serve as the basis for the Passchier-Vermeer work, the 90th percentile is already extrapolated from the 75th percentile.

As stated earlier, the assumption has been made that if a person's hearing loss is severe enough, noise exposure will not make it worse. To be more precise, a person will not incur a hearing loss from a noise that he cannot hear (so long as it is within the audible frequency range). Granting this assumption, it follows that at some percentile, the amount of NIPTS

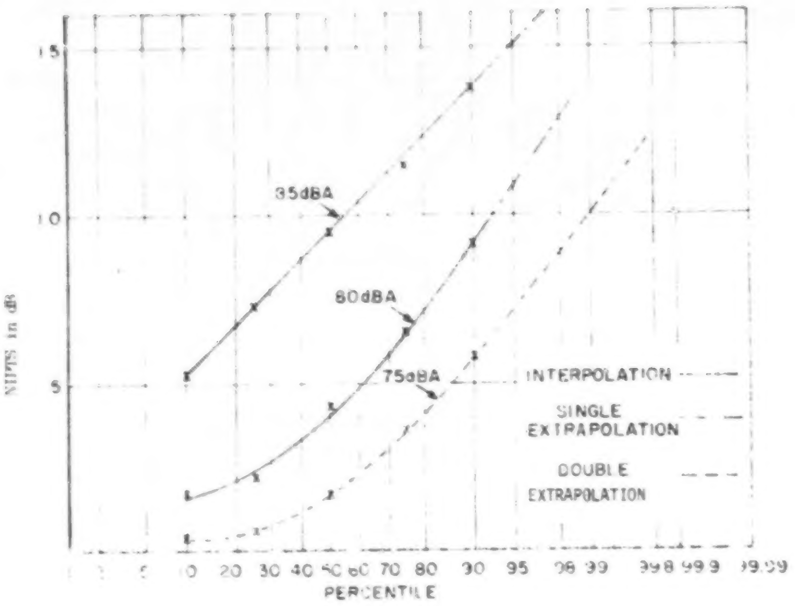


Figure C-2. NIPTS at 4000 Hz across Percentiles for Various 40-yr Exposure Levels[C-2]

for a given exposure level will approach an asymptote. In order for further hearing loss to be incurred above this critical percentile point, greater exposure levels must occur. In the extreme, a person who is totally deaf cannot suffer noise-induced hearing loss.

A study of the data provides a basis for a reasonable estimate of this critical percentile. Baughn's data gives an indication that the population with a hearing level greater than 60 dB after a 40-year exposure begins to become less affected by noise (Figures 9, 10, and 11 of ref. C-2). For example, if a person has a hearing loss greater than 75 dB, it is not reasonable to expect that an A-weighted noise of 75 dB (which normally means that only a level of 65 dB would be present at the octave band centered at 4000 Hz) will cause a further increase of the 75 dB loss. Next, it is necessary to determine the distribution of hearing levels of the non-noise-exposed population at age 60. The best data available are the hearing levels of 60 year-old women of the 1960-62 Public Health Survey.[C-4] While certainly some of the women in the sample may be noise exposed, the noise exposure of that population sample can be considered minor as compared to the apparent noise exposure of men. The data from the Public Health Survey predict the percentage of the population with hearing levels above 70, 75, and 80 dB.

Figure C-3 shows the exposure levels at which no more than 5 dB NIPTS at 4000 Hz will occur for various percentiles on the lowermost curve. The curve labeled PHS-4000 Hz

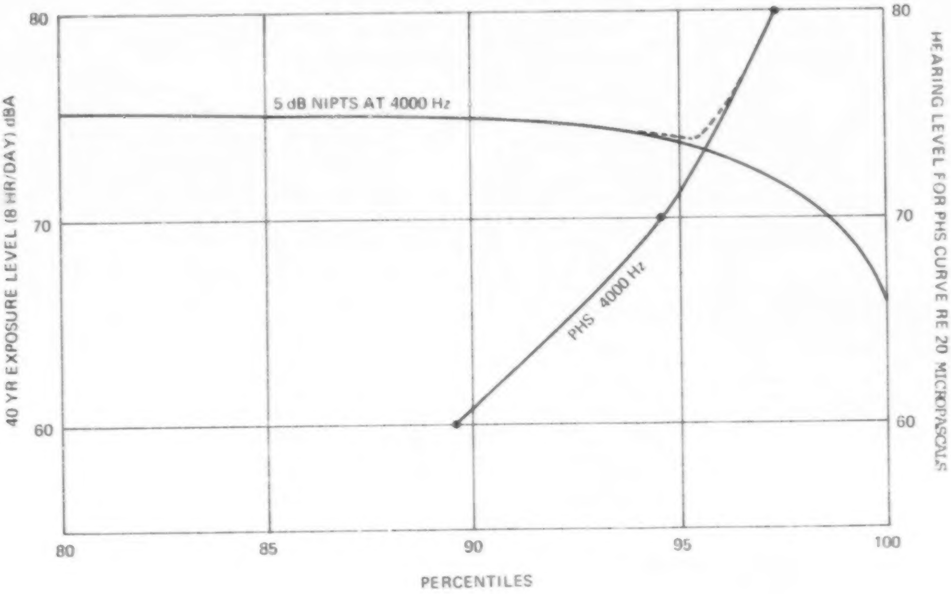


Figure C-3. Exposure Level and Hearing Level as a Function of Population Percentile, Showing the 5 dB NIPTS Curve Merging with the PHS 4000 Hz Curve

represents hearing levels by percentiles of the non-noise exposed population. If a noise level that cannot be heard by an individual is assumed not to change his hearing level, then the extrapolated 5 dB NIPTS curve of Figure C-3 cannot cross the curve labeled PHS. In fact, the 5 dB NIPTS curve must turn upward and merge with the PHS curve, shown in Figure C-3 by the dotted line. The point of merging is seen to be at approximately the 96th percentile and the exposure level required to protect this percentile from a shift of more than 5 dB is an $L_{eq(8)}$ of 72 to 74 dB, or approximately 73 dB. It may be concluded therefore, that a 40-year noise exposure below an $L_{eq(8)}$ of 73 is satisfactory to prevent the entire statistical distribution of hearing levels from shifting at any point by more than 5 dB. Generalizing from these conclusions, the entire population exposed to $L_{eq(8)}$ of 73 is protected against a NIPTS of more than 5 dB.

A similar analysis can be made for 5 dB and 10 dB NIPTS at the mid frequencies (Figure C-4). The upper PHS curve represents the better ear data for the average of 500, 1000 and 2000 Hz of both men and women from the Public Health Survey.[C-4] Both men and women are used since there is little difference due to sex and hearing levels for these frequencies. Considering that the curves will merge in the same manner as the 5 dB at 4000 Hz NIPTS and PHS curves, one can conclude that:

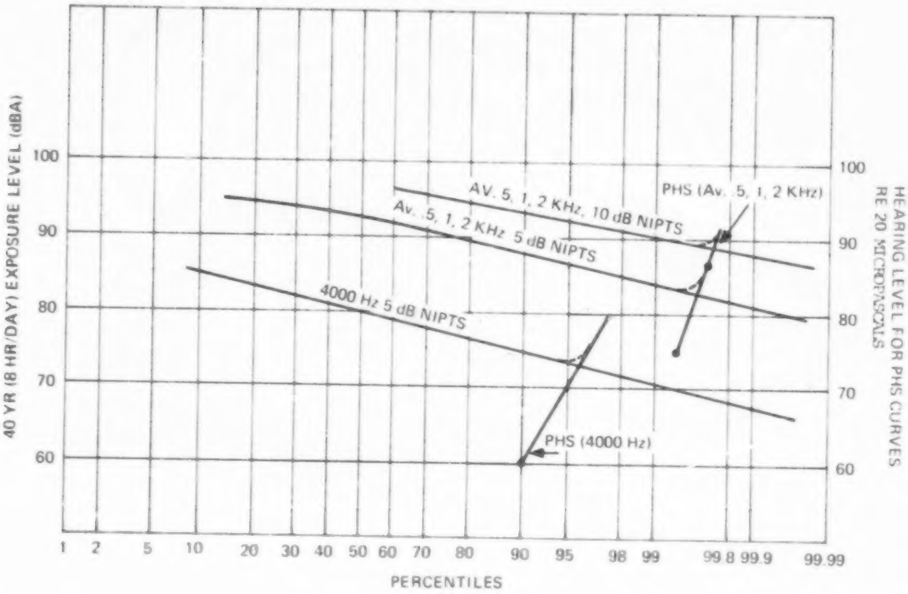


Figure C-4. Exposure Level and Hearing Level as a Function of Population Percent Showing Merging of Different NIPTS Curves with PHS Curves

1. $L_{eq(8)}$ of 84 dB will cause no more than a 5 dB shift at the critical percentile for the averaged frequencies 500, 1000 and 2000 Hz.

2. $L_{eq(8)}$ dB will cause no more than a 10 dB shift at the most critical percentile for the averaged frequencies 500, 1000 and 2000 Hz.

Although the data base used here is quite large, we cannot be absolutely certain that it is representative of the whole population. Any argument such as that presented above does not, in fact, provide 100% protection of the entire population. Obviously, there are a few individuals who might incur more than 5 dB NIPTS for an exposure level of 73 dB. There is the possibility that individuals might shift from lower to higher percentiles with a change in exposure level. In other words, there may be individuals who experience greater shifts in hearing level than those predicted here over periods of time much less than 40 years.

At this point, it may be useful to examine the same data in a slightly different way, without utilizing the concept of the critical percentile. Assuming that the NIPTS of the exposed population are distributed normally, the exposure levels which produce various amounts of NIPTS at the 50th and 90th percentiles may be extrapolated to levels which produce NIPTS at the 99th percentile. Using this extrapolation, Figure C-5 shows NIPTS as

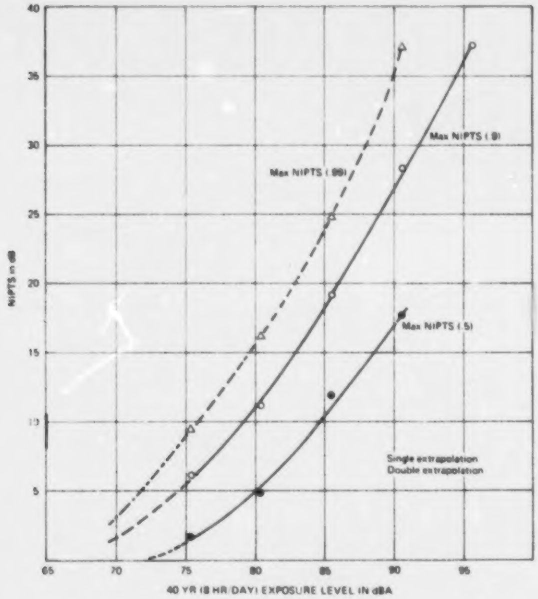


Figure C-5. NIPTS as a Function of Exposure Level for the 50th, 90th and 99th Percentiles

a function of exposure level for the 50th, 90th and 99th percentiles. The 99th percentile curve intersects the 5 dB NIPTS point at 71.5 dB (which is only 1.5 dB below the level previously identified). Thus, if one wishes to protect up to the 99th percentile without employing the concept of the critical percentile, the exposure level necessary to prevent more than 5 dB NIPTS is an $L_{eq(8)}$ of 71.5 dB.

The preceeding analysis utilizing the concept of the critical percentile, concludes that an 8-hour per day exposure to a 73 dB steady noise for 40 years will result in a noise-induced permanent threshold shift of no more than 5 dB at 4000 Hz. This conclusion was reached through the use of assumptions and considerations pointed out earlier in this appendix. Similar analysis of the same and similar data may be made using other assumptions and considerations. Some analyses lead to essentially the same conclusion while others do not. However, no such analysis has identified a level of much less than 65 dB or much greater than 80 dB for the same conditions (i.e., 5 dB NIPTS at 4000 Hz for 40 years of exposure). While the discussion of these levels and their derivations are a subject of great interest and activity in the scientific community, the Administrator of the Environmental Protection Agency is required to identify the level which, in his judgment, is requisite to protect public health and welfare. For that purpose, the level of 73 dB appears to be the most reasonable choice for the conservation of hearing based on the present state of scientific knowledge.

Adjustments for Intermittency and Duration

The next step is to transpose this level into one which will protect public health and welfare, in terms of environmental noise exposure, with an adequate margin of safety. For this purpose, it is necessary to correct for intermittency and to extrapolate to 24 hours. In order to do this, two hypotheses are necessary–the TTS Hypothesis and the Equal Energy Hypothesis.

The TTS Hypothesis states that a temporary threshold shift measured 2 minutes after cessation of an 8-hour noise exposure closely approximates the NIPTS incurred after a 10- to 20-year exposure to that same level. There is a substantial body of data supporting this hypothesis.

The Equal Energy Hypothesis states that equal amounts of sound energy will cause equal amounts of NIPTS regardless of the distribution of the energy across time. While there is experimental confirmation and general acceptance of this hypothesis, certain types of intermittency limit its application.

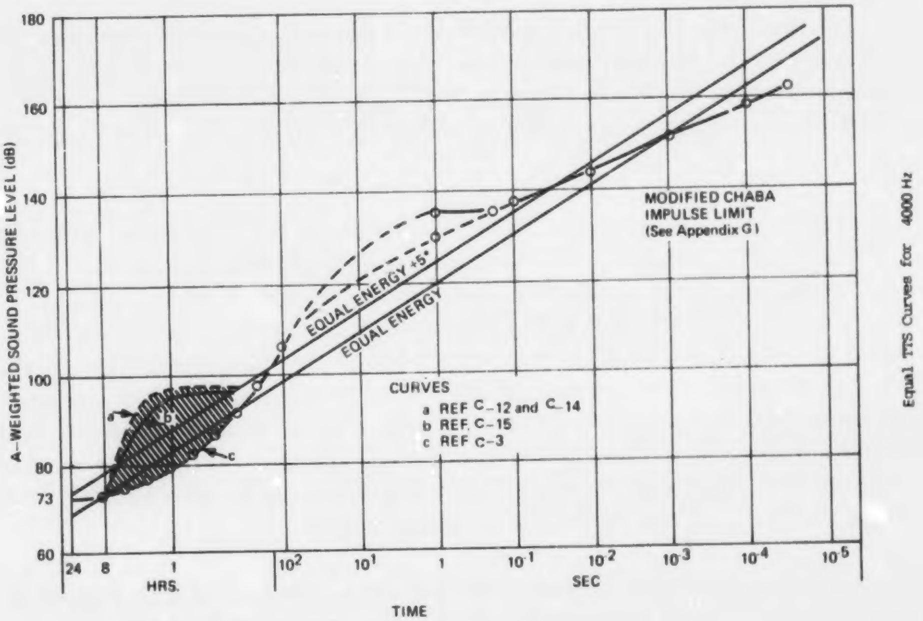
Intermittency

The equal energy concept is considered by some to be a conservative approach for short exposure periods. An alternative approach may be necessary because there is little direct evidence to show the effect of short exposure periods or intermittency on the development of NIPTS. This approach implies the use of temporary threshold shift as a predictor of NIPTS.

Even for a continuous noise, TTS is not predictable for all possible durations using the equal energy rule. The equal energy rule predicts, with reasonable accuracy, the TTS at 4000 Hz for durations of 8 hours down to about 30 minutes. Effects from durations shorter than this, however, are better predicted by a slight deviation from the equal energy rule. While equal energy provides for a 3 dB increase in exposure level for each halving of exposure duration, TTS for durations of less than 30 minutes are better predicted by greater intensities for each halving of time. For instance, TTS for durations of less than 15 minutes are better predicted by a 6 dB rather than a 3 dB increase. For an exposure of two minutes duration, the level required to produce an expected TTS at 4000 Hz would be approximately 10 dB greater than the level predicted by the equal energy concept.

Investigations of environmental noise patterns reported in the EPA document "Community Noise" C-10 indicate that in most environments, noise fluctuates or is intermittent. Moreover, intermittent noise for a given L_{eq} having peak levels of 5 to 15 dB higher than the background level, may produce less hearing damage than a continuous noise with the same energy.[C-11] Also, noise levels which are below 65 dB for 10 percent of the time tend to be less dangerous than continuous noise.[C-12] Therefore, intermittent noise as used in this document will be defined as noise which is below 65 dB for about 10 percent of each hour (i.e., L_{90} of less than 65 dB), with peak levels of 5 to 15 dB higher than the background. From the examples cited in "Community Noise", it is clear that most environmental noise meets these criteria. For this reason, the L_{eq} measured in many situations can be expected to produce less harmful effects on hearing than those depicted in Table C-1. Some correction factor is thus indicated for L_{eq} values describing noise expected in a typical environmental situation in which the exposure is relatively intense but intermittent in nature.

In order to determine an appropriate correction factor, Figure C-6 has been drawn. Using an exposure of 73 dB for 8 hours as a baseline, the sound pressure levels producing equal TTS_2 to be expected at 4000 Hz are plotted for durations of continuous noise as short as 1-1/2 minutes.[C-3] Plotted also (curve a), is the maximum intermittency correction suggested by "Second Intersociety Committee" [C-13] and discussed in the NIOSH criteria document.[C-11] This correction is for the mid frequencies. Recent work has indicated that for 4000 Hz the best intermittency correction to produce equal TTS_2 is represented by curve b.[C-14] The crosshatched area between the curves "a" and "c" signifies the area of uncertainty.



* With 5 dB correction for intermittency added.

NOTE: Impulse noise is defined as $L_{eq} \simeq$ PEAK -9 dB. Shaded area indicates area of uncertainty.

Figure C-6. Equal TTS Curves for 4000 Hz

In addition, TTS curves for impulse noise are included in Figure C-6. Appendix G contains the details of the modified CHABA limit and the conversion necessary to derive from the peak sound pressure level of a decaying impulse the continuous A-weighted noise of the same duration. The impulse noise data show that the equal energy concept is still a reasonable approximation for very short durations. While certainly it may be overly protective for some noise patterns, in general it predicts the effects of noise on hearing reasonably well. Prediction is improved, however, with a 5 dB allowance for intermittency.

The average correction for intermittency suggested by Figure C-6 is 5 dB (i.e., placing the origin of the equal energy line at 78 dB for 8 hours). This correction should be used only if the noise level between events is less than 65 dBA for at least 10 percent of the time ($L_{90} < 65$ dBA). Since most environmental noise exposures will meet this requirement during any 8-hour period, it is further suggested that environmental noise should be considered intermittent unless shown otherwise. Using the 5 dB correction factor, the area of uncertainty (crosshatched) of Figure C-6 is approximately bisected. Further support for such a 5 dB correction factor is found in a recent Swedish study where exposure to continuous noise of L_{eq} 85 to 90 caused a hearing loss which corresponded to an intermittent noise of L_{eq} 90 to 95. The authors conclude that a 5 dB correction factor is appropriate.[C-15]

For certain noise situations, a larger intermittency correction might be justified. However, the use of large corrections when only part of the total noise exposure pattern is known entails a considerably higher chance of error. Therefore, the use of correction factors higher than 5 dB for intermittency are not considered consistent with the concept of an adequate margin of safety.

Conversion of 8-Hour to 24-Hour Exposure Levels

The TTS after 24 hours of exposure generally exceeds that after 8 hours of exposure by about 5 dB.[C-2] Thus the use of a 5 dB correction factor is suggested to extrapolate from the 8-hour exposure data to 24-hour exposure.[C-2] For example, the predicted effects of an exposure to 75 dB steady-state noise for a 24-hour duration are equivalent to the effects estimated from industrial studies for an 8-hour exposure to a continuous noise with a level of 80 dB. This 5 dB correction is consistent with the equal-energy trade-off between exposure duration and noise level. That is, the equal-energy rule in this case also dictates a correction of 5 dB for 24 hours.

It appears that exposures over a period longer than 24 hours need not be considered in this case. Various studies of TTS [C-16,C-17,C-18] have shown that, for an exposure to a specific noise level, TTS will not exceed a limiting value regardless of exposure duration. This limit is reached at approximately 24 hours of exposure. However, this concept applies only to exposure levels less than 85 dB.

Conversion of Occupational Dose to a Full Year (250 to 365 Days)

The applicability of occupational data to non-occupational exposure is questional in several ways. One concern is the use of the occupational exposure data to predict the general effects on populations composed of people who, for a variety of reasons, do not work. However, there are no data from which to derive approximate correction factors. Another concern is the fact that the occupational data are based on a 250-day working year. When predicting the effect of a known noise exposure over the 365-day year, certainly some correction is in order. The equal energy concept would predict at least a 1.6 dB lowering of the exposure level, and such a correction should be used when the concept of an annual exposure dose is used.

To summarize the adjustments, the following exposures over 40 years will result in the same effect:

- L_{eq} of 73 dB continuous noise during the 8-hour working day with relative quiet for the remaining 16 hours, 5 days per week. (See discussion of quiet requirements below).

- L_{eq} of 78 dB intermittent noise during the 8-hour working day with relative quiet for the remaining 16 hours, 5 days per week.
  $73 + 5 = 78$

- L_{eq} of 76.4 dB intermittent noise for 8 hours a day, with relative quiet for the remaining 16 hours, for the 365-day year.
  $78 - 1.6 = 76.4$

- L_{eq} of 71.4 dB intermittent noise for 24 hours a day, 365 days a year.
  $76.4 - 5 = 71.4$

In view of possible uncertainties in the analysis of the data, it is considered reasonable to round down from 71.4 dB to 70 dB. These uncertainties will be discussed in the next section.

CONSIDERATIONS FOR PRACTICAL APPLICATION

The Data Base

In viewing the data in this appendix and elsewhere in the hearing impairment literature, a number of fundamental considerations must be noted:

1. Few, if any, of the various "classic studies" (e.g., those of Robinson, Baughn, and Passchier-Vermeer) are on comparable populations. In addition, some of the data are derived from populations for which noise exposure histories are sketchy, if not absent (e.g., the 1960-62 U.S. Public Health Survey data).

2. There are major questions regarding the comparability of the audiometric techniques used in the various surveys.

3. There are a great number of unanswered questions and areas of uncertainty with regard to the relationship of hearing thresholds to individual physiological and metabolic state. The role of the adequacy of the blood supply to the ear (and the possible influence of changes in that blood supply resulting from cardio-vascular respiratory disease or the process of aging), as well as the fundamentals of cellular physiology involved in adverse effects within the organ of Corti, simply cannot be stated with any degree of reliability at this time. There is some evidence that these non-noise related influences may be of major significance. Moreover, part of the adverse effect of noise on hearing may be attributable indirectly to these influences.

4. There are no large-scale longitudinal studies on hearing loss in selected and carefully followed populations, whose physical state and noise exposure has also been carefully detailed.

Accuracy of Estimated Effects

There is imperfect agreement among various studies as to the exact relationship between sound exposure level and noise-induced hearing loss. The range of error involved is on the order of 5 dB[C-2] when examining the difference between the values in any single study and the values presented in Table C-1. Furthermore, the intermittency correction of 5 dB is only an approximation. It has been proposed that a correction as high as 15 dB could be used in some cases. Thus, the true intermittency correction for a particular noise exposure situation could be from 0 - 15 dB.

The selection of alternative population percentiles to be protected would cause relatively small changes. For instance, there is only a 7 dB difference in protecting the 50th percentile against incurring a 5 dB hearing loss instead of the 96th percentile.

Using the assumption that the noise is of broadband character can lead to errors of 5 to 10 dB by which the risk of the sound exposure is underestimated. This could lead to greater possible errors if a substantial portion of the exposure is to noise with intense pure tone components. These conditions, however, are rare in the environmental situation.

There are apt to be errors in extrapolating beyond the 90th percentile in order to predict effects at higher percentiles. Likewise, there might be errors in extrapolating from known exposure data at 90 and 80 dB to estimated effects at 73 dB for an 8-hour exposure to continuous noise.

One final potential source of error inherent in using the occupational data is the need to compare a population that has received an occupational noise exposure to a population that has not received an occupational noise exposure. However, this latter population may have been exposed to levels of environmental noise (other than occupational). As a consequence in comparing the two groups, occupational exposures may very well show negligible effects below a certain level because other environmental noises predominate. The direction of the possible error is not unequivocally clear, as certainly the adverse effect of many industrial exposures may very well have been due to an unfortunate combination with non-occupational exposures. At this time, it is impossible to properly analyze the possible bias that the non-occupational noise exposure introduces into the data of Table C-1. At present it is assumed to be negligible. This assumption will require ultimate verification by experimentally relating the annual exposure dose of individuals to their hearing level. Only such studies will show how much of what we now tend to contribute to the physiological aging process of the hearing mechanism could be reduced by further reducing what we consider today as "normal" or "quiet" environmental noise levels associated with present-day living in our society.

Quiet Requirements

It has been shown that the quiet intervals between high intensity noise-bursts must be below 60 dB SPL for the octave band centered at 4000 Hz if recovery from temporary threshold shift at 4000 Hz is to be independent of the resting sound pressure level.[C-20] In this document, sound pressure level of 50 dB in the 4000 Hz octave band is suggested as a goal for "effective quiet". For typical spectra of community noise, 50 dB SPL in the 4000 Hz octave band translates to an A-weighted sound level of approximately 60 dB. Thus, for purposes of hearing conservation, the noise level where an individual sleeps should not be above an L_{eq} of 60 dB, based on the following considerations:

1. Total TTS recovery is required to prevent TTS from becoming NIPTS.

2. For some individuals, an 8-hour nighttime period is the only available recovery period.

3. In order to be consistent with the identified level of $L_{eq(24)} = 70$, an 8-hour exposure of 75 dB would require an exposure of 60 dB or less for the remaining 16 hours.

It should be noted that this level would be too high to protect against other effects. (See Appendix D).

Contribution of Outdoor Noise to the Total Exposure in Residential Areas

A person's 24-hour exposure to outdoor noise will typically include both outdoor and indoor exposures. Since a building reduces the level of most intruding outdoor environmental noises by 15 dB or more (windows partially open), an outdoor L_{eq} will not adequately predict hearing effects, because the corresponding NIPTS estimates will be too high. Consider a situation where the average sound level is 70 dB outdoors and 55 dB indoors. The effective noise exposures for some of the possible exposure situations are:

24-hour L_{eq} in dB (assuming the noise is generated outdoors)

Indoor Time (55 dB)	Outdoor Time (70 dB)	Combined Indoor and Outdoor	Outdoor Only
24 hrs	0 hrs	55.0	
23	1	58.6	56.2
22	2	60.5	59.2
21	3	61.8	61.0
20	4	62.9	62.2
16	8	65.5	65.2
8	16	68.3	68.2
0	24	70	70

The 24-hour value of the combined L_{eq} is essentially unchanged from the outdoor value (less than one dB) by the indoor noise exposure, so long as the outdoor exposure exceeds 3 hours. Thus, as long as the criterion is established with respect to outdoor noise exposure exceeding 3 hours per day, the contribution of the indoor level of intruding outdoor noise may be neglected in computing the 24 hour L_{eq}. This conclusion does not depend greatly on the actual noise attenuation provided by the house so long as the attenuation is greater than 10 dB.

Relation of L_{dn} to L_{eq} in Residential Areas

Although in residential areas, or in areas where individuals may be expected to be present for prolonged periods of time, it would appear desirable for practical considerations to use only one measure of noise, such as L_{dn}, it may be misleading to do so. The difficulty arises from the fact that to relate hearing loss to noise exposure, the basic element to consider is the actual energy (not weighted) entering the ear during a twenty-four hour period. L_{eq} measures the actual energy entering the ear whereas L_{dn} includes a 10 dB weighting for the nighttime period. Thus, L_{dn} values corresponding to actual L_{eq} values are dependent upon the distribution in noise levels occurring during the total twenty-four hour period and could be misleading. For example, the L_{dn} values corresponding to $L_{eq(8)}$ are between 0 to 6 dB greater than the L_{eq} values. The lower value corresponds to a situation where the average sound level during the night is 10 dB lower than that occurring during the day, whereas the higher value corresponds to the situation when the average sound level during the night equals that occurring during the day. In residential areas, the difference in L_{eq} values for the daytime and nighttime period often is approximately 4 dB based on community noise measurements.[C-20] In this particular case, this difference in L_{eq} values leads to an L_{dn} value which is three decibels above the L_{eq} value for the daytime period.

REFERENCES FOR APPENDIX C

C-1. French, N.R. and Steinberg, J.C., "Factors Governing the Intelligibility of Speech Sounds," *Journal of Acoustical Society of America*, 19:90-119, 1947.

C-2. Johnson, D.L., "Prediction of NIPTS Due to Continuous Noise Exposure," EPA-550/9-73-001-B or AMRL-TR-73-91, July 1973.

C-3. Kryter, K.D., Ward, W.D., Miller, J.D. and Eldredge, D.H., "Hazardous Exposure to Intermittent and Steady-State Noise," *Journal of Acoustical Society of America*, 39:451-464, 1966.

C-4. National Center for Health Statistics, *Hearing Levels of Adults by Age and Sex, United States, 1960-1972.* Vital and Health Statistics, PHS Pub. No. 1000-Series 11-No. 11. Public Health Service, Washington, D.C., U.S. Government Printing Office, October 1965.

C-5. Robinson, D.W., "The Relationship Between Hearing Loss and Noise Exposure," Aero Report Ae 32, National Physical Laboratory, England, 1968.

C-6. National Center for Health Statistics, *Hearing Levels of Children by Age and Sex.* Vital and Health Statistics. PHS Pub. No. 1000 Series 11-No. 102. Public Health Service, Washington, D.C., February 1970.

C-7. Guignard, J.C., "A Basis for Limiting Noise Exposure for Hearing Conservation," EPA 550/9-73-001-A or AMRL TR-73-90, July 1973.

C-8. Passchier-Vermeer, W., "Hearing Loss Due to Steady-State Broadband Noise," Report No. 35, Institute for Public Health Engineering, The Netherlands, 1968.

C-9. Baughn, W.L., "Relation Between Daily Noise Exposure and Hearing Loss as Based on the Evaluation of 6835 Industrial Noise Exposure Cases," in publication as AMRL-TR-73-53, Wright-Patterson Air Force Base, Ohio.

C-10. Eldred, K.M., "Community Noise," EPA NTID 300.3, December 1971.

C-11. "Occupational Exposure to Noise, Criteria for a Recommended Standard," U.S. Department of Health, Education and Welfare, National Institute for Occupational Safety and Health, 1972.

C-12. Kryter, K.D., *Effects of Noise on Man*, Academic Press, New York, 1970.

C-13. Guideline for Noise Exposure Control, *Sound and Vibration*, Vol. 4, pp. 21-24, November 1970.

C-14. Ward, W.D., "On the Trading Relation Between Time and Intensity for Intermittent Noise Exposures," presented at 86th Meeting of Acoustical Society of America, October 1973.

C-15. Johansson, B., Kylin, B., and Reopstorff, S., "Evaluation of the Hearing Damage Risk from Intermittent Noise According to the ISO Recommendations," *Proceedings of the International Congress of Noise as a Public Health Problem*, Dubrovnik, Yugoslavia, EPA 550/9-73-008, May 1973.

C-16. Carder, H.M. and Miller, J.D., "Temporary Threshold Shifts from Prolonged Exposure to Noise," *Journal of Speech and Hearing Research*, 13:603-623, 1972.

C-17. Mills, J.H. and Talo, S.A., "Temporary Threshold Shifts Produced by Exposure to Noise," *Journal of Speech and Hearing Research*, 15:624-631, 1972.

C-18. Melnick, W., "Investigation of Human Temporary Threshold Shift (TTS) from Noise Exposure of 16 Hours Duration," paper presented at Meeting of Acoustical Society of America, 1972.

C-19. Ward, W.D., "The Concept of 'Effective Quiet'," presented at the 85th Meeting of the Acoustical Society of America, April 1973.

C-20. "Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure," Environmental Protection Agency, NTID 73.4, July 27, 1973.

Appendix D

NOISE INTERFERENCE WITH HUMAN ACTIVITIES AND RESULTING OVERALL ANNOYANCE/HEALTH EFFECTS

Appendix D

NOISE INTERFERENCE WITH HUMAN ACTIVITIES AND RESULTING OVERALL ANNOYANCE/HEALTH EFFECTS

Environmental noise may interfere with a broad range of human activities in a way which degrades public health and welfare. Such activities include:

1. Speech Communication in Conversation and Teaching.
2. Telephone Communication.
3. Listening to TV and Radio Broadcasts.
4. Listening to Music.
5. Concentration During Mental Activities.
6. Relaxation.
7. Sleep.

Interference with listening situations (items 1-4) can be directly quantified in terms of the absolute level of the environmental noise and its characteristics. The amount of interference in non-listening situations (e.g.,) is often dependent upon factors other than the physical characteristics of the noise. These may include attitude towards the source of an identifiable noise, familiarity with the noise, characteristics of the exposed individual, and the intrusiveness of the noise.

The combination of the various interference effects results in an overall degradation of total well-being. Maximum noise levels that do not affect human well-being must be derived from the body of information on human behavioral response to various noise environments.

SPEECH INTERFERENCE

Speech communication has long been recognized as an important requirement of any human society. It is one of the chief distinctions between humans and other species. Interference with speech communication disturbs normal domestic or educational activities, creates an undesirable living environment, and can sometimes be a source of extreme annoyance. Continued long-term annoyance is considered to affect individual as well as public health and welfare in a variety of ways.

Noise can disturb speech communication in situations encountered at work, in vehicles, at home, and in other settings. Of chief concern for the purposes of this report, is the effect of noise on face-to-face conversation indoors and outdoors, telephone use, and radio or television enjoyment.

The extent to which environmental noise affects speech communication depends on the location (whether indoors or outdoors), the amount of noise attenuation provided by the exterior walls when indoors (including windows and doors), and the vocal effort of the talkers. Certainly, it is possible to maintain communication in the face of intruding noise if the voice level is raised, but in an ideal environment, one should not have to increase the voice level above that which is comfortable in order to communicate easily.

Research since the late 1920's has made great progress in quantitatively characterizing the effects of noise on speech perception. A review of that work is contained in references D-1 and D-2, and it is summarized here as the basis for the maximum environmental noise levels compatible with public health and welfare identified in Section 4 of this report.

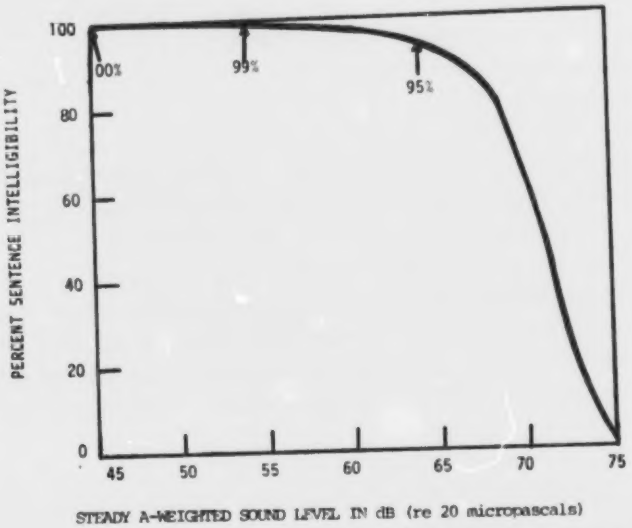
The chief effect of intruding noise on speech is to mask the speech sounds and thus reduce intelligibility. The important contributants to intelligibility in speech sounds cover a range in frequency from about 200 to 6000 Hz, and at each frequency a dynamic level range of about 30 dB. The intelligibility of speech will be nearly perfect if *all* these contributions are available to a listener for his understanding. To the extent that intruding noise masks out or covers some of these contributions, the intelligibility deteriorates more rapidly the higher the noise level, particularly if the noise frequencies coincide with the important speech frequencies.

It is no accident, from an evolutionary point of view, that the hearing of humans is most sensitive in the frequency range most important for the understanding of speech. Therefore, it is not mere coincidence that the A-weighting, designed to reflect the frequency sensitivity of the human ear, should also be useful as a measure of the speech interference potential of intruding noise. A-weighting gives greatest weight to those components of the noise that lie in the frequency range where most of the speech information resides, and, thus, yields higher readings (A-weighted levels) for noises in most of the 200 to 6000 Hz range than does the overall sound pressure level. A-weighted sound levels will be used throughout this appendix unless otherwise noted.

The principal results of relevant speech research can be utilized for practical application to provide the levels of noise that will produce varying degrees of masking as a function of average noise level and the distance between talkers and listeners. Other factors such as the talker's enunciation, the familiarity of the listener with the talker's language, the listener's motivation and, of course, the normality of the listener's hearing also influence intelligibility. This value is consistent with the upper end of the range of levels of steady state sound recommended by prior authors in Table D-10 (to be discussed later) as "acceptable" for design purposes for homes, hotels, motels, small offices, and similar spaces where speech communication is an expected and important human activity.

Indoor Speech Interference Due to Steady Noise

The effects of masking normally-voiced speech indoors are summarized in Figure D-1, which assumes the existence of a reverberant field in the room. This reverberant field is the result of reflections from the walls and other boundaries of the room. These reflections enhance speech sounds so that the decrease of speech level with distance found outdoors occurs only for spaces close to the talker indoors. At distances greater than 1.1 meters from the talker, the level of the speech is more or less constant throughout the room. The distance from the talker at which the level of the speech decreases to a constant level in the reverberant part of the room is a function of the acoustic absorption in the room. The greater the absorption, the greater the distance over which the speech will decrease and the lower the level in the reverberant field for a given vocal effort. The absorption in a home



NOTE: Assumes 300 sabins absorption typical of living rooms and bedrooms and is valid for distances greater than one meter.

Figure D-1. Normal Voice Sentence Intelligibility as a Function of the Steady Background Sound Level in an Indoor Situation[D-1, D-2, & D-4] will vary with the type and amount of furnishings, carpets, drapes and other absorbent materials. It is generally least in bathrooms and kitchens and greatest in living rooms, with typical values ranging between 150 and 450 sabins. A typical value for living rooms and bedrooms is 300 sabins. For this value of absorption, the distance to the reverberant field from the talker is slightly greater than one meter, as stated above.

As shown in Figure D-1, the maximum sound level that will permit relaxed conversation with 100% sentence intelligibility throughout the room (talker-listener separation greater than approximately 1.1 meter) is 45 dB.

Outdoor Speech Interference Due to Steady Noise

The sound level of speech outdoors generally continues to decrease with increasing distance between talker and listener with the absence of reflecting walls which provide the reverberance found indoors. Figure D-2 presents the distances between talker and listener for satisfactory outdoor conversations, in different steady background noise levels (A-weighted), for three degrees of vocal effort. This presentation depends on the fact that the voice level at the listener's ear (outdoors) decreases at a predictable rate as the distance between talker and listener is increased. In a steady background noise there comes a point, as the talker and listener increase their separation, where the decreasing speech signal is masked by the noise.

The levels for normal and raised-voice "satisfactory conversation" plotted in the figure do not permit perfect sentence intelligibility at the indicated distances; instead, the sentence intelligibility at each distance is 95 percent, meaning that 95 percent of the key words in a group of sentences would be correctly understood. Ninety-five percent sentence intelligibility usually permits reliable communication because of the redundancy in normal conversation. That is, in normal conversation, some unheard words can be inferred if they occur in particular, familiar contexts. Moreover, the vocabulary is often restricted, which also helps understanding. Therefore, 95 percent intelligibility is satisfactory for most situations.

The levels given in Figure D-2 for relaxed conversation permit 100% speech intelligibility when communicating in a normal voice. This situation represents an ideal environment for speech communication and is considered necessary for acceptable conversation in the indoor environment. However, it does not define the situation outdoors where 95% intelligibility is adequate, and communication outdoors generally takes place between people who are walking or standing relatively close together, about 1 or 2 meters. Moreover, these levels appear to be consistent with the need for speech privacy.

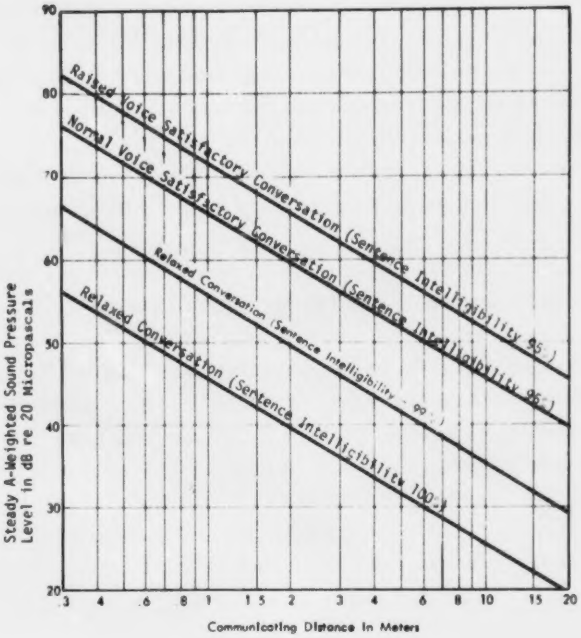


Figure D-2. Maximum Distances Outdoors Over Which Conversation is Considered to be Satisfactorily Intelligible in Steady Noise.[D-1, D-2]

The data for normal and raised voice of Figure D-2 are tabulated for convenience below:

Table D-1

STEADY A-WEIGHTED NOISE LEVELS THAT ALLOW COMMUNICATION WITH 95 PERCENT SENTENCE INTELLIGIBILITY OVER VARIOUS DISTANCES OUTDOORS FOR DIFFERENT VOICE LEVELS[D-2]

VOICE LEVEL COMMUNICATION DISTANCE (meters)

	0.5	1	2	3	4	5
Normal Voice (dB)	72	66	60	56	54	52
Raised Voice (dB)	78	72	66	62	60	58

If the noise levels in Figure D-2 and Table D-1 are exceeded, the speaker and listener must either move closer together or expect reduced intelligibility. For example, consider a conversation at a distance of 3 meters in a steady background noise of 56 dB using normal voice levels. If this background level is increased from 56 to 66 dB, the speakers will either need to move from 3 to 1 meter separation to maintain the same intelligibility, or alternatively, to raise their voices well above the raised-voice effort. If they remain 3 meters apart without raising their voices, the intelligibility would drop from 95 to 65 percent.

Speech Interference in the Presence of Fluctuating Sound Levels

The data in Figures D-1 and D-2 are based on tests involving steady, continuous sound. It might be questioned whether these results would apply to sounds which have fluctuating levels. For example, when intermittent noise intrusions, such as those from aircraft flyovers or truck passbys, are superimposed on a steady noise background, the equivalent sound level is greater than the level of the background alone. If the sound levels of Figure D-1 and D-2 are interpreted as equivalent sound levels, it could be argued that these values could be slightly increased (by an amount depending on the statistics of the noise), because most of the time the background noise level is actually lower than the equivalent sound level.

The amount of this difference has been calculated for the cases of urban noise and aircraft noise statistics shown in Figure D-3. The data in this figure[D-3] include a wide range of urban sites with different noise levels and an example of aircraft noise at a site near a major airport. In each case the speech intelligibility was calculated from the standard sentence intelligibility curve[D-4] for various values of L_{eq}, first with steady noise and then with the two specific fluctuating noises of Figure D-3. The calculation consisted of determining the incremental contribution to sentence intelligibility for each level (at approximately 2 dB increments) and its associated percentage of time occurrence. The incremental contributions were then summed to obtain the total value of intelligibility in each case.

The results, shown in Table D-2, demonstrate that, for 95 percent sentence intelligibility, normal vocal effort, and 2 meter separation between talker and listener outdoors, the maximum L_{eq} value associated with continuous noise is less than the maximum value for an environmental noise whose magnitude varies with time. It is therefore concluded that almost all time-varying environmental noises with the same L_{eq} would lead, averaged over long time periods, to better intelligibility than the intelligibility for the same L_{eq} values of continuous noise.

Alternatively, for a fixed L_{eq} value, the percentage of interference with speech (defined as 100 minus the percentage sentence intelligibility) is greater for steady noise than

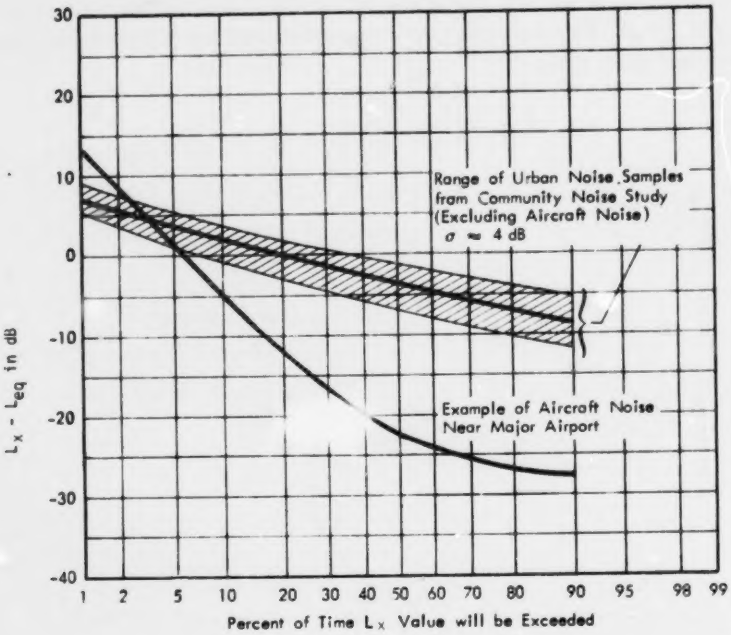


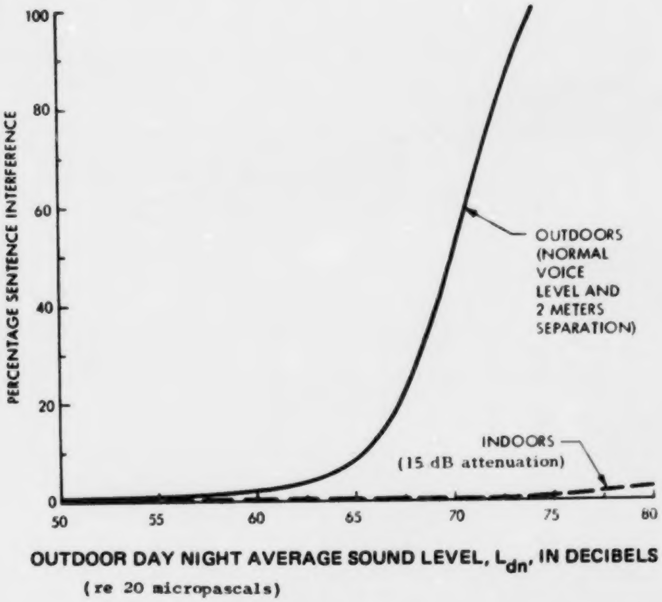
Figure D-3. Cumulative Distribution of Typical Community Noises During the Daytime Relative to the Equivalent Sound Level.[D-39]

Table D-2

MAXIMUM EQUIVALENT SOUND LEVELS THAT ALLOW 95 PERCENT SENTENCE INTELLIGIBILITY AT A DISTANCE OF 2 METERS USING NORMAL VOICE EFFORT OUTDOORS
(From Figures D-2 and D-3)

Noise Type	L_{eq} in decibels
Steady	60
Urban Community Noise	60 +
Aircraft Noise	65

for almost all types of environmental noise whose magnitude varies with time. The relationship between L_{dn} and the *maximum* percentage sentence interference (i.e., for continuous noise) is given in Figure D-4.



NOTE: Percentage interference equals [illegible] minus percentage intelligibility, and L_{dn} is based on $L_d + 3$.[D-39]

Figure D-4. Maximum Percentage Interference with Sentences as a Function of the Day-Night Average Noise Level.

The extreme example of a fluctuating noise is a series of noise pulses of constant level that are of sufficient magnitude relative to the background to control the equivalent sound level. For example, there could be a case where the background noise during the off-cycle is assumed negligible, so that when the noise pulses are not present, the speech intelligibility is 100 percent. Table D-3 shows how the percentage interference with sentence intelligibility varies as a function of the level and on-time for a cycled steady noise whose level and duration are always adjusted to yield a fixed value for the equivalent sound level. Two situations are envisaged: indoors, relaxed conversation, $L_{eq} = 45$ dB, leading to 100 percent sentence intelligibility in the steady, continuous noise; and outdoors, normal voice effort at 2 meters separation, $L_{eq} = 60$ dB, leading to 95 percent sentence intelligibility in the steady, continuous noise.

Table D-3

PERCENTAGE INTERFERENCE WITH SENTENCE INTELLIGIBILITY IN THE PRESENCE OF A STEADY INTRUDING NOISE CYCLED ON AND OFF PERIODICALLY IN SUCH A WAY AS TO MAINTAIN CONSTANT EQUIVALENT SOUND LEVEL, AS A FUNCTION OF THE MAXIMUM NOISE LEVEL AND DURATION[D-39]

(Assumes 100% intelligibility during the off-cycle)

Situation	A-Weighted level of intruding noise during "on-cycle," decibels	Duration of intruding noise as percent of total time	Percent interference if intruding noise were continuous	Average percent interference in cycled noise
INDOORS Relaxed conversation, background L_{eq} = 45 dB, 100% intelligibility if background noise were continuous at 45 dB	45	100	0	0
	50	32	0.5	0.16
	55	10	1	0.10
	60	3	2	0.06
	65	1	6	0.06
	70	0.3	40	0.12
	75	0.1	100	0.10
	80	0.03	100	0.03
OUTDOORS Normal voice at 2 meters, background L_{eq} = 60 dB, 95% intelligibility if background noise were continuous at 60 dB	60	100	5	5.0
	65	32	7.7	2.5
	70	10	53	5.3
	75	3	100	3.0
	80	1	100	1.0

The combination of level in the first column and duration in the second column are such as to maintain constant L_{eq} for each situation, 45 dB indoors and 60 dB outdoors. The third column gives the percent interference with sentence intelligibility that would apply if the noise were steady and continuous with the level indicated in column 1. The fourth column gives the percent interference for the cycled noise in each case.

The results for this extreme case indicate that no matter how extreme the noise fluctuation for the indoor case, on the average there is negligible speech interference for L_{eq} = 45 dB. On the other hand, with L_{eq} = 60 dB outdoors, the average speech interference tends to decrease as the fluctuations of the noise become more extreme. However, it should be recognized that if the duration of the intruding noise were to take place in one continuous period, and if its percentage interference (column 3) were equal to 100, then it would blot out all communication for the duration of its "on-cycle".

The following sections relating to activity interference, annoyance, and community reaction utilize equivalent sound level with a nighttime weighting (L_{dn}) which is discussed more fully in Appendix A. However, for the speech interference effects of noise, a similar measure without the nighttime weighting (L_{eq}) has been employed. To allow comparison between the various effects stated above, some relationships are necessary to allow at least approximate conversion from L_{eq} to L_{dn}. For indoor levels such as those described in Appendix A for various lifestyles, levels during the day are at least 10 dB higher than those during the night. Thus L_{eq} is virtually the same as L_{dn} for normal indoor situations.

For an outdoor L_{dn} of 55 dB or less, day time levels (L_d) are generally 8 dB higher than the nighttime levels (L_n). For this situation, L_{dn} is still quite close to L_{eq} during the day. The correction is less than one dB. For levels greater than L_{dn} 65 dB, the nighttime levels are generally only 4 dB less than during the day time. For these cases, L_{dn} is 3 dB higher than L_{eq} during the day.

For values of L_{dn} between 55 and 65, further interpolation is necessary using Figure A-7.

ACTIVITY INTERFERENCE

Activity interference due to noise is not new. The recent EPA document concerning public health and welfare criteria for noise[D-5] mentions an ordinance enacted 2500 years ago by the ancient Greek community of Sybaris, banning metal works and the keeping of roosters within the city to protect against noise that interfered with speech and might disturb sleep. History contains other examples indicating speech and sleep interference due to various types of noises, ranging from wagon noise to the noise of blacksmiths.

More recently, surveys have been conducted which further demonstrate that noise does interfere with various types of activity. For example, Figures D-5 and D-6, based on research done in England, give activity interference reported by the people who were disturbed by aircraft noise for various types of activities as a function of the approximate L_{dn} associated with noise from aircraft flyovers [D-14] (for explanation of the term L_{dn} see Appendix A). Thus, for an outside L_{dn} of approximately 55 dB, over 50% of the people who were disturbed reported some interference with TV sound, and 45% reported some interference with conversation. At the same level, about 45% reported that noise occasionally woke them up, while 30% claimed it sometimes disturbed their relaxation. The figures also indicate that at higher noise levels, greater percentages of people who were disturbed have reported activity interference.

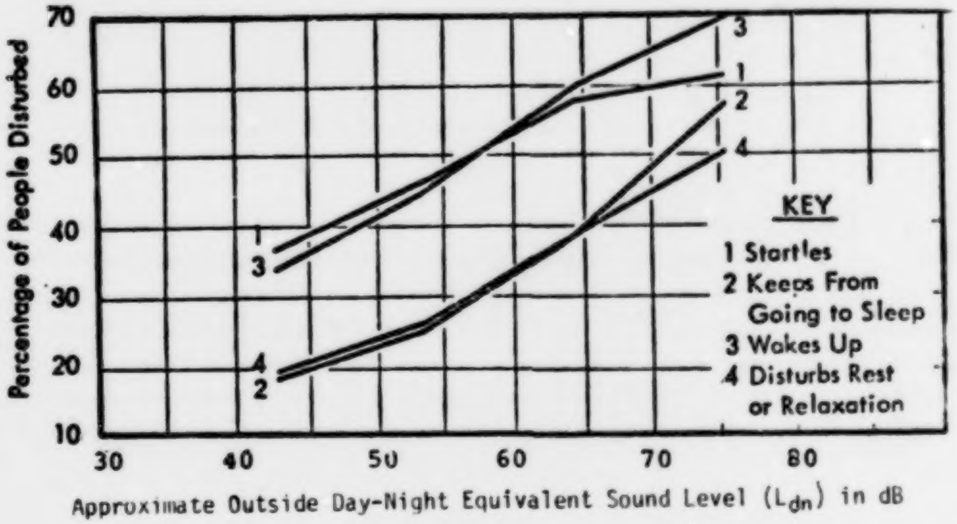


Figure D-5. Percentage of People Disturbed by Aircraft Noise for Various Types of Reasons Concerned With Rest And Sleep [D-6]

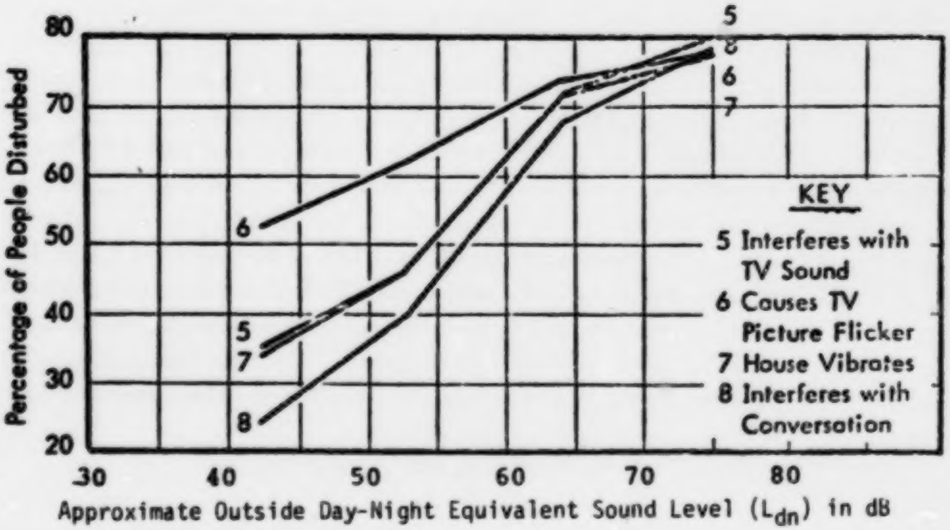


Figure D-6. Percentage of People Disturbed by Aircraft Noise for Various Types of Reasons Concerned with Domestic Factors[D-6]

Later research in the USA [D-7] provides the information on activity interference shown in Table D-4. This table gives the activity disturbance percentages of those who reported that they were *extremely disturbed* by the noise, which accounts in part for the low percentage values. It was reported that the daily activities of 98.6% of those questioned (about 4000 people) were disrupted one or more times by aircraft noise. More activities are mentioned in Table D-4 than in the previous tables. For example, telephone use, reading, listening to tapes and records, and eating were reported to have been disturbed by noise.

A study performed in the Netherlands[D-8] gives further evidence that activity interference is associated with noise (see Table D-5). The data were taken in the urban/suburban areas in the vicinity of the Amsterdam Airport where the L_{dn} ranged from 45 to 85 dB. Activity interference is shown by percentage of people interviewed who have been frequently or sometimes disrupted in various activities. Also reported are the estimated tolertance limits for various portions of the exposed population. Thus, in an area where

Table D-4

PERCENT OF THOSE PEOPLE WHO WERE EXTREMELY DISTURBED BY AIRCRAFT NOISE*, BY ACTIVITY DISTURBED[D-7]

Activity	Percent
TV/Radio reception	20.6
Conversation	14.5
Telephone	13 8
Relaxing outside	12.5
Relaxing inside	10.7
Listening to records/tapes	9.1
Sleep	7.7
Reading	6.3
Eating	3.5

*Percent scoring 4 or 5 on a 1–5 scale.

noise produces "predominantly moderate nuisance," the "tolerance limit" is reached for one-third of the population. Thirty-one percent report being sometimes disturbed by noise during conversation, and 21% report being sometimes disturbed by noise during sleep; occupational disturbance was reported by 12%. (The judgment of "admissibility" with respect to well-being in Table D-5 is the result of the referenced study and not a conclusion of this report.)

A recent study[D-9] in the USA found that 46% of the 1200 respondents were annoyed by surface vehicle noise at some time. Activities which were reported disturbed are indicated by percentages shown in Table D-6. Here we see that sleeping is the activity most disturbed by surface vehicle noise, followed in order by listening to TV, radio or recordings; mental activity, such as reading, writing or thinking; driving; conversing; resting and walking.

From the studies reported here, it is clear that noise does indeed interfere with various activities in our everyday lives. Unfortunately, most of the studies do not provide activity interference as a function of noise exposure. However, the activity which is most sensitive to noise in most of the studies is speech communication (including listening to TV), which can be directly related to the level of the intruding noise.

Table D-5

PERCENTAGE OF PERSONS INTERROGATED WHO FEEL THAT THEY HAVE FREQUENTLY, (F) OR SOMETIMES, (S) BEEN DISTURBED IN CONVERSATION, RADIO LISTENING, TELEVISION, OCCUPATIONS, SLEEP; FEEL AFRAID, AND OF PERSONS IN WHOSE EXPERIENCE ON THESE OCCASIONS THE HOUSE VIBRATES. AT MEAN VALUE OF THE NUISANCE SCORES.[D-8]

Mean Nuisance Score ↓	Disturbance of Conversation		Disturbance of Radio Listening		Disturbance of Television		Disturbance of Occupations		Afraid
	F*	S*	F	S	F	S	F	S	YES
0	0	0	0	0	0	0	0	0	0
1	7	12	2	4	6	10	1	3	25
2	16	24	5	8	12	18	3	7	48
3	27	31	10	15	20	23	7	12	66
4	39	35	18	22	31	25	11	19	78
5	56	37	27	30	42	26	19	28	91
6	67	31	38	36	57	26	34	39	94
7	83	17	56	44	72	28	55	45	100

*F denotes "frequently" S denotes "sometimes"

Table D-5 (Continued)

House Vibrates	Disturbance of Sleep		Nuisance Felt Subjectively	Admissibility from point of view of physical, mental and social well being, in regard to which the stress is laid on disturbance of sleep, disturbance of conversation and feeling afraid
YES	F	S		
0	0	0	No nuisance	—
21	3	7	Slight nuisance	Admissible
41	6	14	Slight to moderate nuisance	Admissible; the tolerance limit is reached for about one-fifth of the population.
56	12	21	Predominantly moderate nuisance	Limit of admissibility; the tolerance limit is reached for about one-third of the population.
72	20	28	Predominantly serious nuisance	Inadmissible; the tolerance limit is exceeded for about half of the population.
83	31	33	Serious nuisance	Inadmissible; the tolerance limit is exceeded for about two-thirds of the population.
92	44	42	Intolerable	Absolutely inadmissible
100	72	28	Intolerable	Absolutely inadmissible

Table D-6

ACTIVITIES OF RESPONDENTS DISTURBED BY SURFACE VEHICLE NOISE

(All Situations: Respondent's Usual Activity)[D-9]

Category	No. of Situations	Percentage of Total Situations
Driving	47	7
Walking	16	2
Talking with people present	42	6
Working at home	12	2
Reading, writing, thinking	80	12
Sleeping	155	22
Other	13	2
Not relevant	179	26
Listening to TV, radio, records	92	13
Resting (awake)	35	5
Not ascertained	22	3
Total	693	100

COMMUNITY REACTION TO ENVIRONMENTAL NOISE

There are two methods of indirectly assessing the cumulative effects of environmental noise on people. These are examining the reactions of individuals or groups of individuals to specific intruding noises, either (a) with respect to actions taken (complaints, suits, etc.), or (b) in terms of responses made to social survey questionnaires. The first category, involving overt action by individuals or groups, is summarized in this section, and key data regarding the second category, involving responses indicating annoyance, is summarized in the next section.

In the last 25 years, many new types of noise sources have been introduced into suburban and urban residential communities. These sources, such a jet aircraft, urban freeways, new industrial plants, and homeowner equipment, have created numerous community problems with environmental noise. These problems have provided significant data and insight relating to community reaction and annoyance and stimulated the development of several indices for measurement of the magnitude of intruding noises.

Various U.S. Governmental agencies began to investigate the relationships between aircraft noise and its effect on people in communities in the early 1950's. This early research resulted in the proposal of a model by Bolt, Rosenblith and Stevens [D-10] for relating aircraft noise intrusion and the probable community reaction. This model, first published by the Air Force, accounted for the following seven factors:

1. Magnitude of the noise with a frequency weighting relating to human response.
2. Duration of the intruding noise.
3. Time of year (windows open or closed).
4. Time of day noise occurs.
5. Outdoor noise level in community when the intruding noise is not present.
6. History of prior exposure to the noise source and attitude toward its owner
7. Existence of pure-tone or impulsive character in the noise.

Correction for these factors were initially made in 5 dB intervals since the magnitudes of many of the corrections were based solely on the intuition of the authors, and it was considered difficult to assess the response to any greater degree of accuracy. [D-11-13] This model was incorporated in the first Air Force Land Use Planning Guide[D-14] in 1957 and was later simplified for ease of application by the Air Force and the Federal Aviation Administration.

Recently the day-night sound level has been derived for a series of 55 community noise problems [D-3] to relate the normalized measured L_{dn} with the observed community reaction. The normalization procedure followed the Bolt, Rosenblith and Stevens method with a few minor modifications. The correction factors which were added to the measured L_{dn} to obtain the normalized L_{dn} are given in Table D-7. The distribution of the cases among the various noise sources having impact on the community are listed in Table D-8. The results are summarized in Figure D-7.

The "no reaction" response in Figure D-7 corresponds to a normalized outdoor day-night sound level which ranges between 50 and 61 dB with a mean of 55 dB. This mean value is 5 dB below the value that was utilized for categorizing the day-night sound level for a "residential urban community," which is the baseline category for the data in the figure. Consequently, from these results, it appears that no community reaction to an intruding noise is expected, on the average, when the normalized day-night sound level of an identifiable intruding noise is approximately 5 dB less than the day-night sound level

Table D-7

CORRECTIONS TO BE ADDED TO THE MEASURED DAY-NIGHT SOUND LEVEL (L_{dn}) OF INTRUDING NOISE TO OBTAIN NORMALIZED L_{dn}[D-3]

Type of Correction	Description	Amount of Correction to be Added to Measured L_{dn} in dB
Seasonal Correction	Summer (or year-round operation)	0
	Winter only (or windows always closed)	–5
Correction for Outdoor Noise Level Measured in Absence of Intruding Noise	Quiet suburban or rural community (remote from large cities and from industrial activity and trucking)	+10
	Normal suburban community (not located near industrial activity)	+5
	Urban residential community (not immediately adjacent to heavily traveled roads and industrial areas)	0
	Noisy urban residential community (near relatively busy roads or industrial areas)	–5
	Very noisy urban residential community	–10
Correction for Previous Exposure & Community Attitudes	No prior experience with the intruding noise	+5
	Community has had some previous exposure to intruding noise but little effort is being made to control the noise. This correction may also be applied in a situation where the community has not been exposed to the noise previously, but the people are aware that bona fide efforts are being made to control the noise.	0
	Community has had considerable previous exposure to the intruding noise and the noise maker's relations with the community are good	–5
	Community aware that operation causing noise is very necessary and it will not continue indefinitely. This correction can be applied for an operation of limited duration and under emergency circumstances.	–10
Pure Tone or Impulse	No pure tone or impulsive character	0
	Pure tone or impulsive character present	+5

Table D-8

NUMBER OF COMMUNITY NOISE REACTION CASES AS A FUNCTION OF NOISE SOURCE TYPE AND REACTION CATEGORY

Type of Source	Community Reaction Categories			Total Cases
	Vigorous Threats of Legal Action	Wide Spread Complaints	No Reaction or Sporadic Complaints	
Transportation vehicles, including:				
Aircraft operations	6	2	4	12
Local traffic			3	3
Freeway	1			1
Rail		1		1
Auto race track	2			2
Total Transportation	9	3	7	19
Other single-event or intermittent operations, including circuit breaker testing, target shooting, rocket testing and body shop	5			
Steady state neighborhood sources, including transformer substations, residential air conditioning	1	4	2	7
Steady state industrial operations, including blowers, general manufacturing, chemical, oil refineries, et cetera	7	7	10	24
Total Cases	22	14	19	55

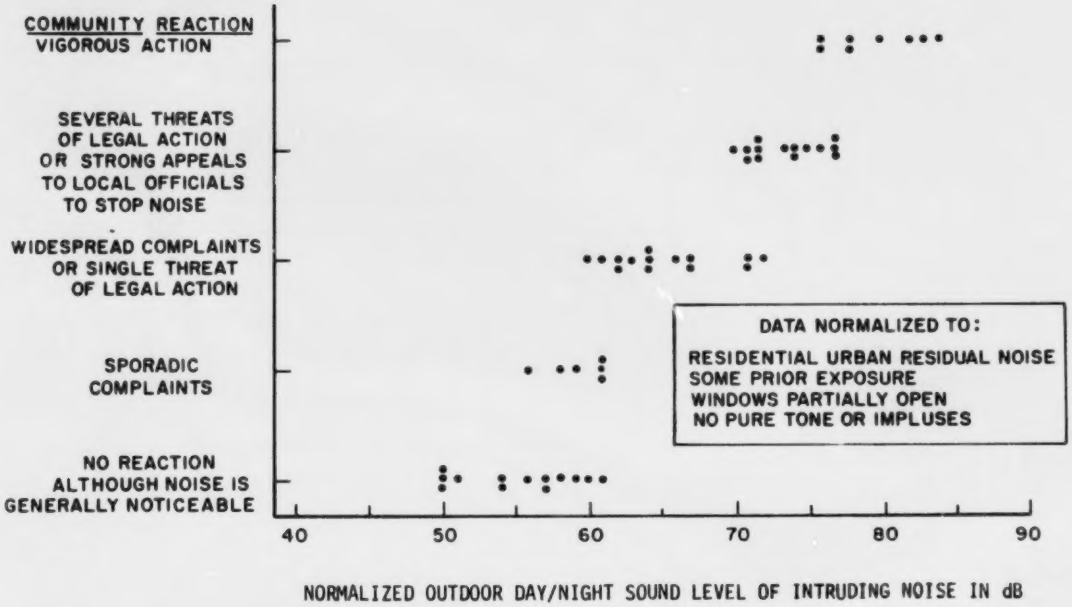


Figure D-7. Community Reaction to Intensive Noises of Many Types as a Function of the Normalized Outdoor Day Night Sound Level of the Intruding Noise [D-3]

that exists in the absence of the identifiable intruding noise. This conclusion is not surprising; it simply suggests that people tend to judge the magnitude of an intrusion with reference to the noise environment that exists without the presence of the intruding noise source.

The data in Figure D-7 indicate that widespread complaints may be expected when the normalized value of the outdoor day-night sound level of the intruding noise exceeds that existing without the intruding noise by approximately 5 dB, and vigorous community reaction may be expected when the excess approaches 20 dB. The standard deviation of these data is 3.3 dB about their means and an envelope of ±5 dB encloses approximately 90 percent of the cases. Hence, this relationship between the normalized outdoor day-night sound level and community reaction appears to be a reasonably accurate and useful tool in assessing the probable reaction of a community to an intruding noise and in obtaining one type of measure of the impact of an intruding noise on a community.

The methodology applied to arrive at the correlation between normalized L_{dn} and community complaint behavior illustrated in Figure D-7 is probably the best available at present to predict the most likely community reaction in the U.S. Unfortunately, readiness to complain and to take action is not necessarily an early indicator of interference with activities and annoyance that the noise creates. The fact that correction for the normal background noise level without intruding noise results in better correlation of the data points might be interpreted to mean that urban communities have adapted to somewhat higher residual noise levels that are not perceived as interfering or annoying. On the other hand, it is more likely that the higher threshold for complaining is caused by the feeling that higher residual noise is unavoidable in an urban community and that complaining about "normal" noise would be useless. For the present analysis, it might therefore be more useful to look at the same data without any corrections for background noise, attitude, and other subjective attributes of the intruding noise. Figure D-8 gives these data for the same 55 cases.

The increase in spread of the data is apparent in comparing Figures D-7 and D-8, and the standard deviation of the data about the mean value for each reaction is increased from 3.3 dB for the normalized data to 7.9 dB. The mean value of the outdoor day-night sound level associated with "no reaction" is 55 dB; with vigorous reaction, 72 dB; and, for the three intermediate degrees of reaction, 62 dB.

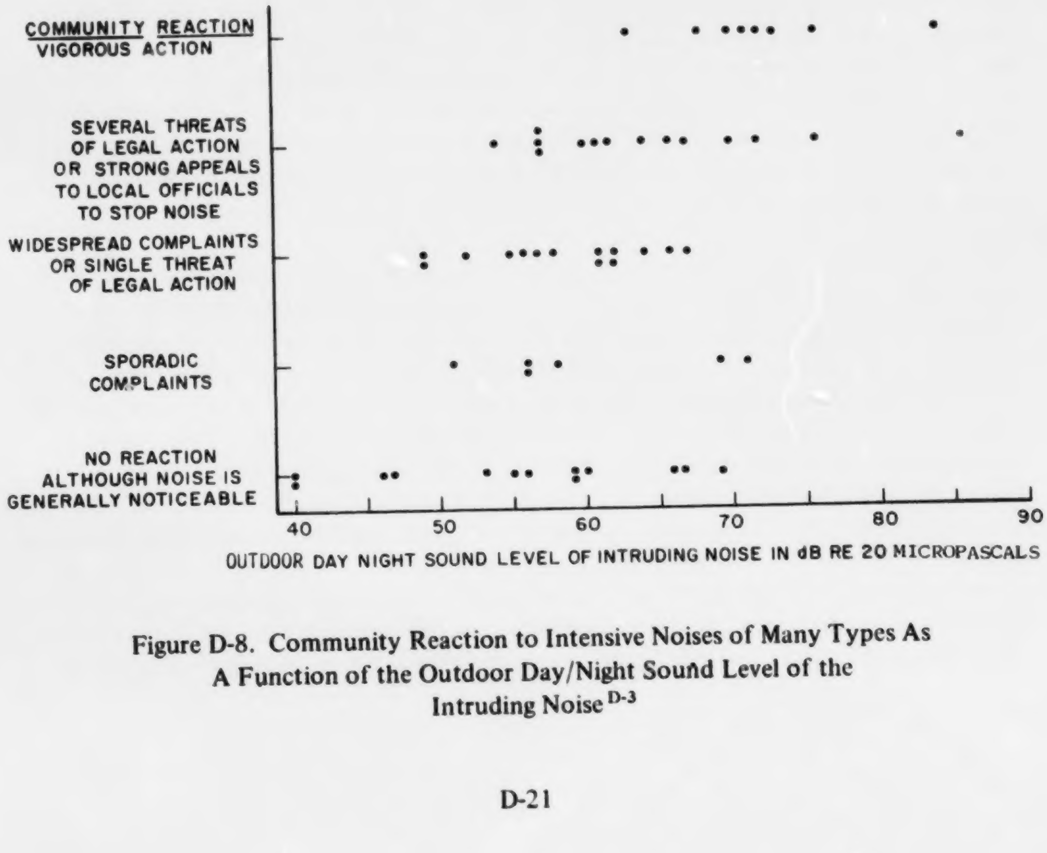


Figure D-8. Community Reaction to Intensive Noises of Many Types As A Function of the Outdoor Day/Night Sound Level of the Intruding Noise[D-3]

There is no evidence in these 55 cases of even sporadic complaints if the L_{dn} is less than 50 dB.

ANNOYANCE

Annoyance discussed in this report is limited to the long-term integrated adverse responses of people to environmental noise. Studies of annoyance in this context are largely based on the results of sociological surveys. Such surveys have been conducted among residents of a number of countries including the United States.[D-6,D-7,D-15,D-16]

The short-term annoyance reaction to individual noise events, which can be studied in the field as well as in the laboratory, is not explicitly considered, since only the accumulating effects of repeated annoyance by environmental stimuli can lead to environmental effects on public health and welfare. Although it is known that the long-term annoyance reaction to a certain environment can be influenced to some extent by the experience of recent individual annoying events, the sociological surveys are designed to reflect, as much as possible, the integrated response to living in a certain environment and not the response to isolated events.

The results of sociological surveys are generally stated in terms of the percentage of respondents expressing differing degrees of disturbance or dissatisfaction due to the noisiness of their environments. Some of the surveys go into a complex procedure to construct a scale of annoyance. Others report responses to the direct question of "how annoying is the noise?" Each social survey is related to some kind of measurement of the noise levels (mostly from aircraft operations) to which the survey respondents are exposed, enabling correlation between annoyance and outdoor noise levels in residential areas.

The results of social surveys show that individual responses vary widely for the same noise level. Borsky [D-17] has shown that these variances are reduced substantially when groups of individuals having similar attitudes about "fear" of aircraft crashes and "misfeasance" of authorities are considered. Moreover, by averaging responses over entire surveys, almost identical functional relationships between human response and noise levels are obtained for the whole surveyed population as are obtained for the groups of individuals having *neutral* attitudinal responses. Therefore, in deriving a generalized relationship between reported annoyance and day-night sound level, it seems reasonable to use the average overall group responses, recognizing that individuals may vary considerably from the average, both positively and negatively depending upon their particular attitudinal biases. In most cases, the average group response can also be interpreted as the average individual's response during his life period. That is to say, each individual changes his attitudinal biases according to various factors and personal experiences not necessarily connected to the noise or even to the environment in general, which lead to fluctuations of each individual's attitude. The average group response does, to some extent, express the individual's response averaged over longer periods of his life. Therefore, this response reflects the effects most likely to affect his health over a longer time period.

A comparison of the results of three of the most prominent social surveys around airports are presented in the following paragraphs. These are the first and second surveys around London's Heathrow Airport,[D-6,D-15] and the Tracor study [D-7] around eight major airports in the United States. The noise level data reported for each survey were converted to outdoor day-night sound levels for the purpose of this analysis. In addition, data are presented from a survey of response to motor vehicles in U.S. urban areas.[D-18]

First London-Heathrow Survey

The first survey of about 2,000 residents in the vicinity of Heathrow airport was conducted in 1961 and reported in 1963.[D-6] The survey was conducted to obtain responses of residents exposed to a wide range of aircraft flyover noise. A number of questions were used in the interviews to derive measures of degrees of reported annoyance. Two results of this survey are considered here.

A general summary of the data, aggregating all responses on a category scale of annoyance ranging from "not at all" to "very much annoying," is plotted as a function of approximate L_{dn} in Figure D-9. This figure presents a relationship between word descriptors and day-night sound level.

Among the respondents in every noise level category, a certain percentage were classified in the "highly annoyed" category. This percentage of each group is plotted as a function of approximate L_{dn} on Figure D-10.

Comparison of the data on the two figures reveals that, while the average over the population would fit a word classification of "little annoyed" at an L_{dn} value of approximately 60 dB, more than 20% of the population would still be highly annoyed at this L_{dn} value.

In addition to the derivation of overall annoyance scales, this study examined the attitude of the people towards their area and their desire to move as a function of both noise level and several other factors. The results are summarized in Figs. D-11 and D-12. They indicate that when the approximate L_{dn} exceeded 66-68 dB, aircraft noise became the reason most often cited by those who either "liked their area less now than in the past" or "wanted to move". Further, the data indicate that aircraft noise was of little importance,

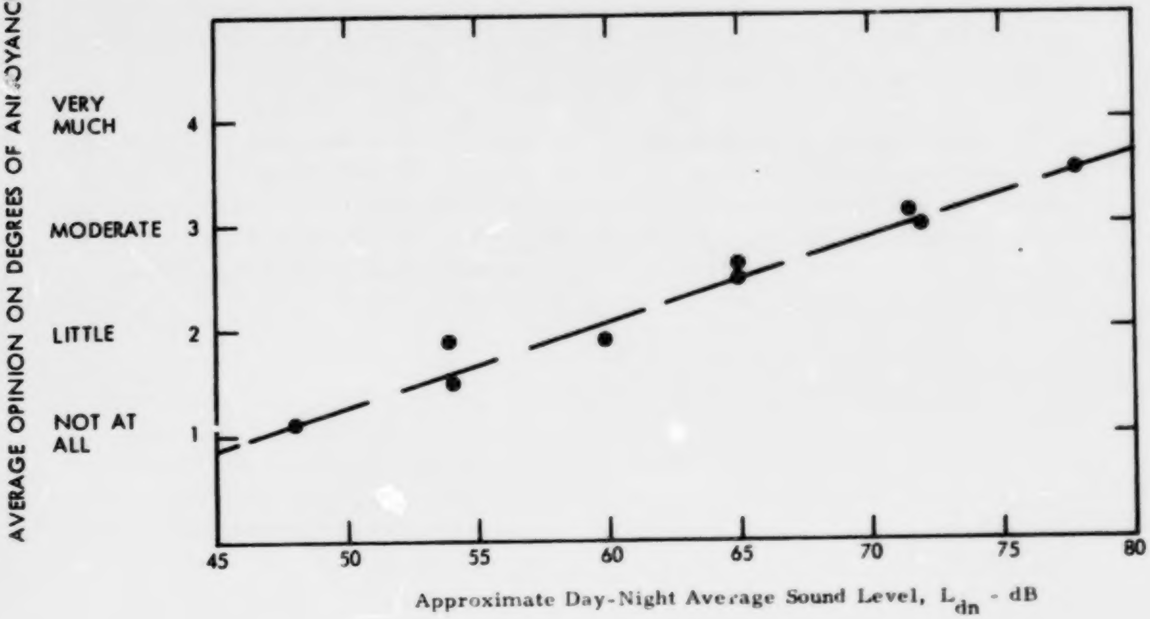


Figure D-9. Average Degree of Annoyance as a Function of the Approximate Day-Night Noise Level – Results of First London Heathrow Survey [D-39 from D-6]

compared to other environmental factors, when the approximate L_{dn} was below 53 dB and was of average importance as a factor when the approximate L_{dn} was 60 dB.

Results of Second London Survey and Tracor Surveys

In 1967, a second survey[D-15] was taken around Heathrow Airport in the same general area as the first survey. While refinements were attempted over the first survey, the results were generally the same. In 1971, the results of an intensive three year program under NASA sponsorship which studies eight air carrier airports in the United States were reported by Tracor.[D-7] Since each of these efforts is discussed in detail in the references, only an analysis of their combined results is considered here. Borsky[D-17] used the data from these studies to correlate annoyance with noise exposure level for people having different attitudinal characteristics and different degrees of annoyance.

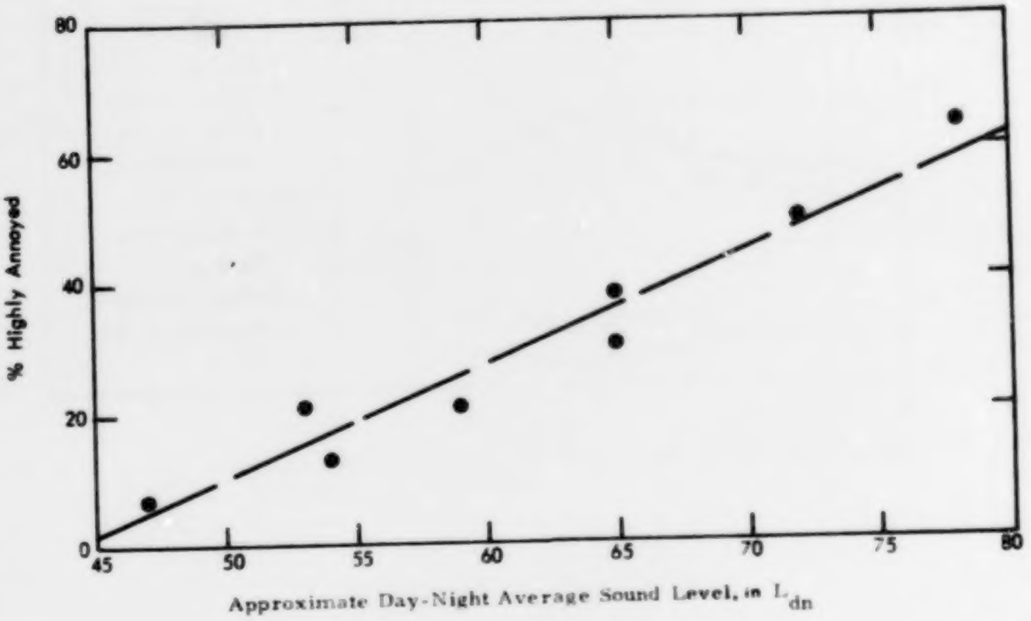


Figure D-10. Percentage Highly Annoyed as Function of Approximate Day-Night Noise Level – Results of First London Heathrow Survey[D-39 from D-6]

Utilizing Borsky's data for "moderate" responses to the attitudes of "fear" and "misfeasance", the relationship between percent highly annoyed and noise exposure level is plotted on Figure D-13. Again, noise levels have been converted to approximate L_{dn} values. It is worth noting that more than 7500 respondents are included in the data sets from which the computations were derived.

The comparison between the results shown on Figures D-10 and D-13 is striking in the near identity of the two regression lines–indistinguishable at any reasonable level of statistical confidence. The importance of these two sets of data lies in the stability of the results even though the data were acquired 6 to 9 years apart, at nine different airports in two different countries. This complete agreement led to the proposal of an average curve for the nominal relationship between sound level and percentage of people annoyed, which has been coordinated among and used by various U.S. Government agencies,[D-19] applied in the studies of ICAO's coordinating committee on aircraft noise; and verified by a recent analysis of British, French and Dutch survey results conducted by the Organization for Economic Cooperation and Development (OECD).[D-20] According to the OECD work,

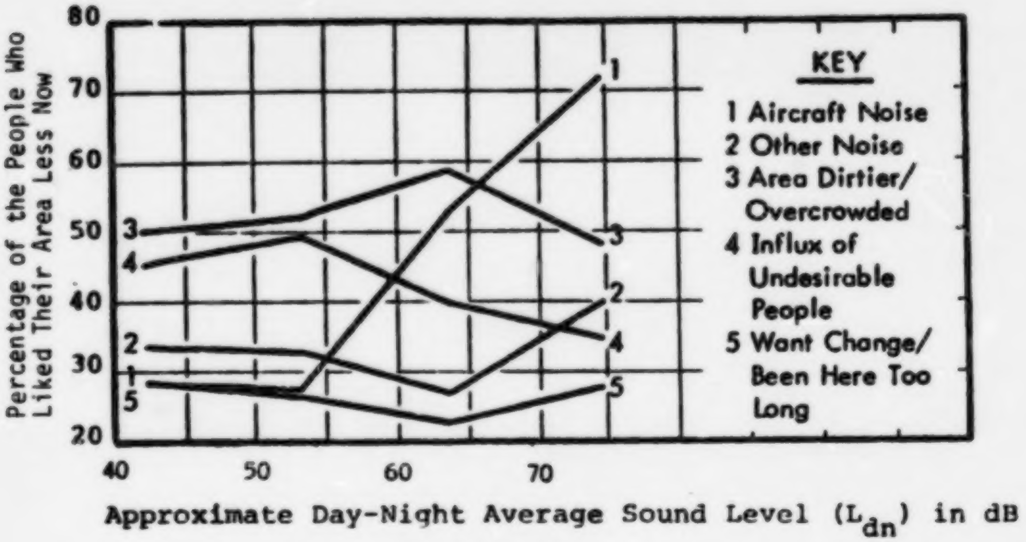


Figure D-11. Percentage of People Liking Their Area Less Now than in the Past for Various Reasons D-6

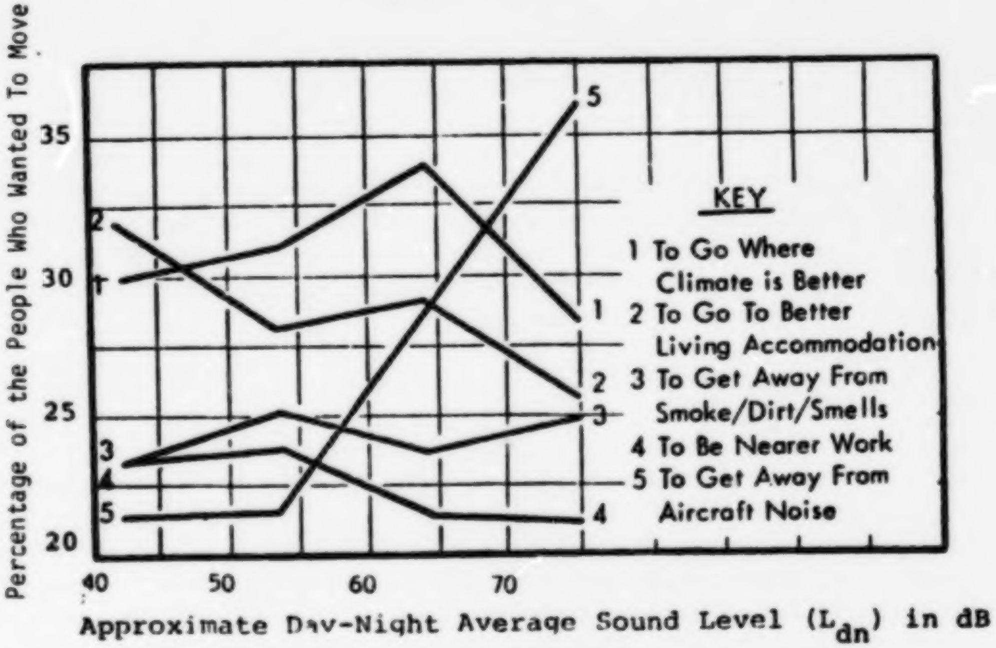


Figure D-12. Percentage of People Giving Particular Reasons for Wanting to Move D-6

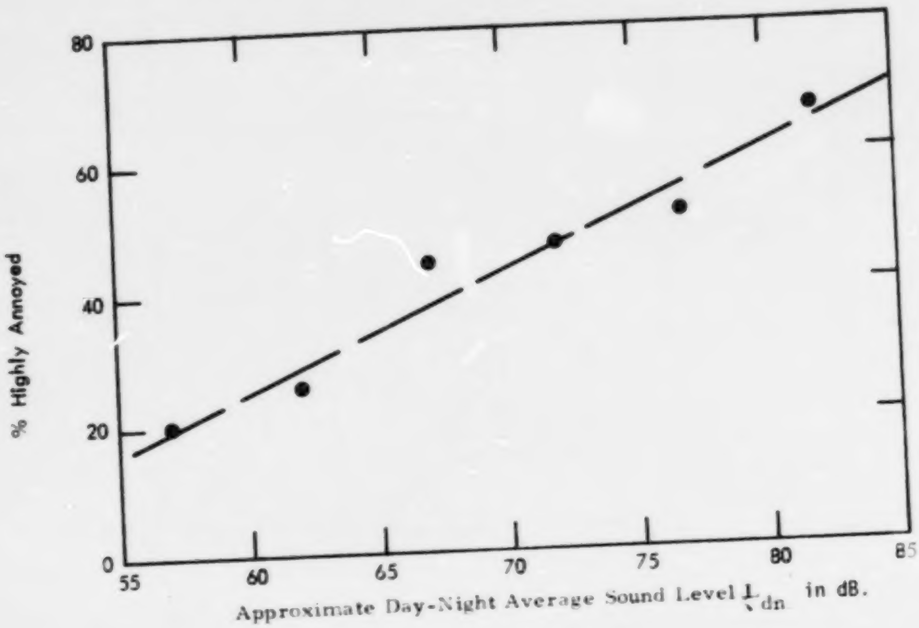


Figure D-13. Combined Results–British and U.S. Surveys[D-17]

the percentage of annoyed people can be predicted as follows: Percentage of annoyed people = 2 (L_{dn} - 50).

The results of the Tracor Study[D-7] also give a relationship between the number of people who indicate in a social survey that they are highly annoyed and the number of people who indicate that they have ever complained about the noise to any one in authority. The results, presented in Figure D-14, indicate that when 1% of the people complain, 17% report being highly annoyed; and when 10% of the people complain, 43% are highly annoyed.

Judgement of Noisiness at Urban Residential Sites

In 1972, a study of urban noise was conducted primarily to evaluate motor vehicle noise for the Automobile Manufacturers Association.[D-9] As part of this survey, 20 different urban-suburban residential locations *not in the vicinity of airports* were studied in Boston, Detroit, and Los Angeles. Noise measurements were acquired and a social survey of 1200

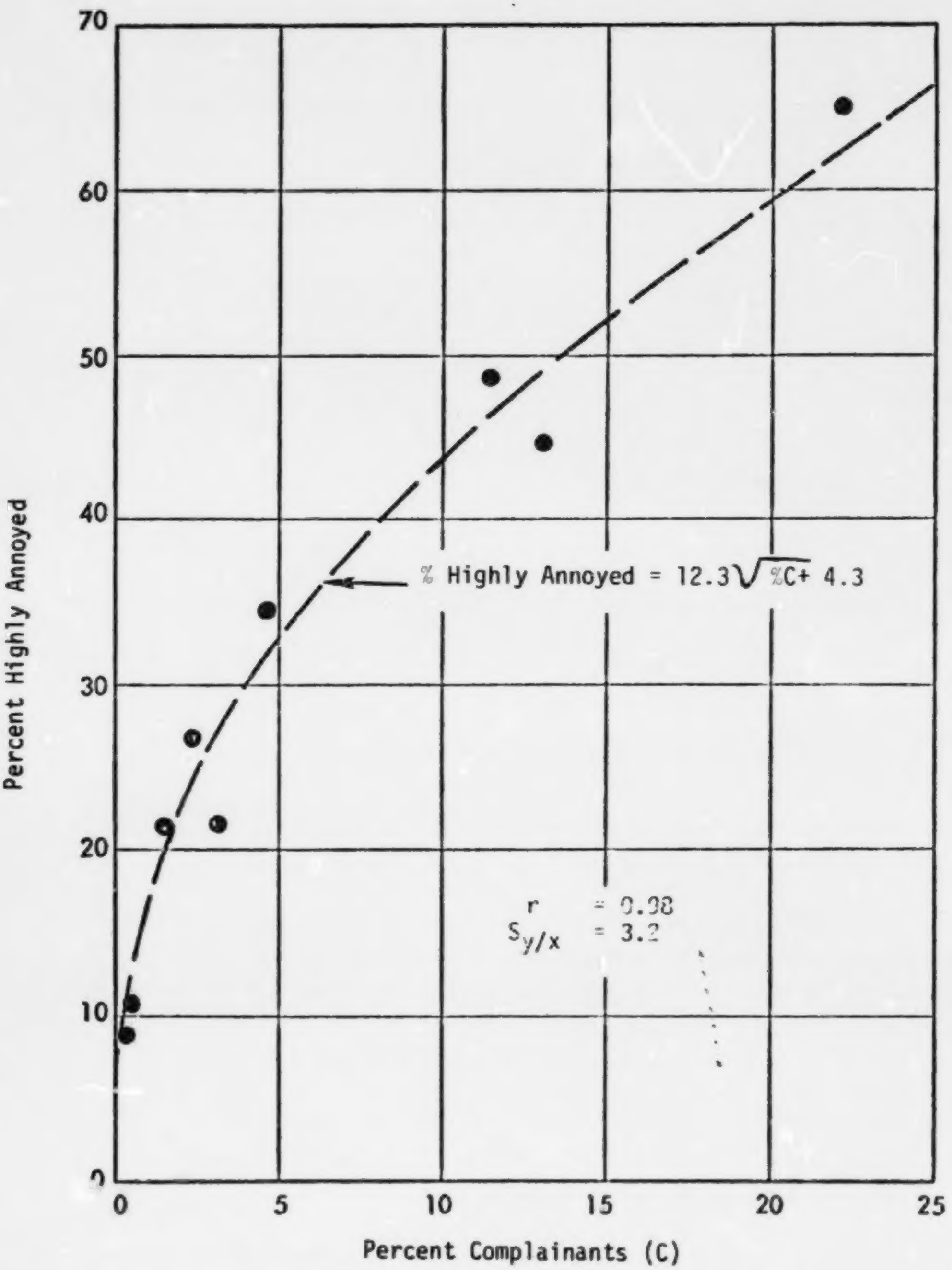


Figure D-14. Percentage of Highly Annoyed As A Function of Percent of Complainants D-7 respondents was conducted. Part of the survey was directed towards obtaining the respondents' judgement, on a category scale, of the exterior noisiness at their places of residence.

The averaged judged noisiness values per site are plotted on Figure D-15 as a function of measured L_{dn} values. The significance of these "non-aircraft" data is the comparison they permit with other survey data acquired exclusively around airports. Intercomparison of these data with previous data indicate that for an L_{dn} value of 60 dB, the site would be judged "quite" noisy. The average annoyance for a group would be classed as "little," but about 25% of the people would still claim to be highly annoyed.

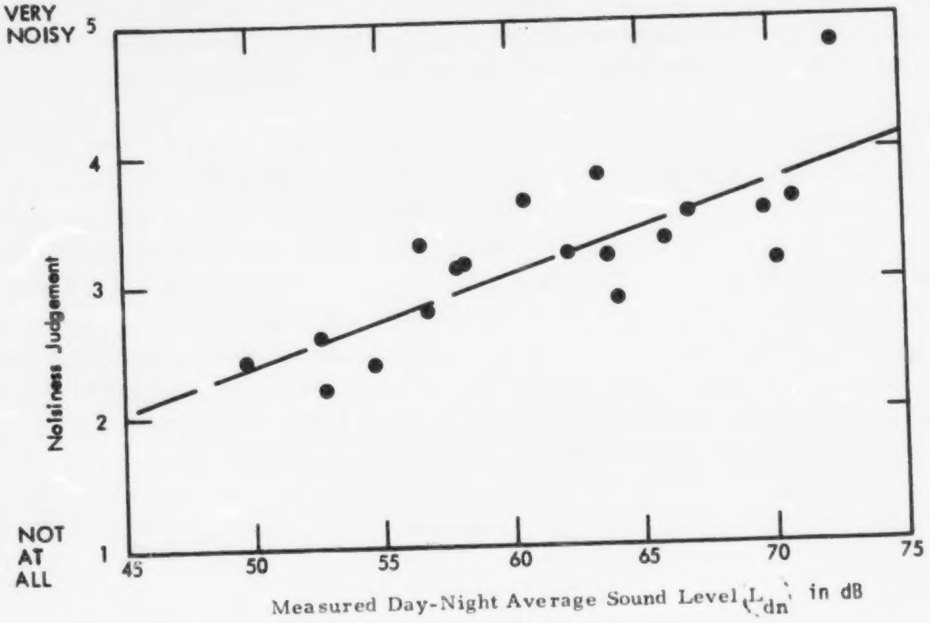


Figure D-15. Judged Noisiness at Automobile Manufacturers Association Survey Sites[D-9]

When all respondents, irrespective of exposure site, were asked whether they were annoyed by motor vehicle noise, 53% were not annoyed, while 46% were, with an average intensity of annoyance of 4.2 on a scale where 3 stood for "quite annoying," 4 for "definitely annoying" and 5 "strongly annoying." Of the 46% of respondents who stated they were annoyed by motor vehicle noise, 77% experienced annoying noises while in their homes, 12% while in transit, and only 5% at work.

This indication, that the principle annoyance with environmental noise occurs in the residential situation is further confirmed in the results of the London City Noise Survey [D-18] summarized in Table D-9.

Summary of Annoyance Survey Results

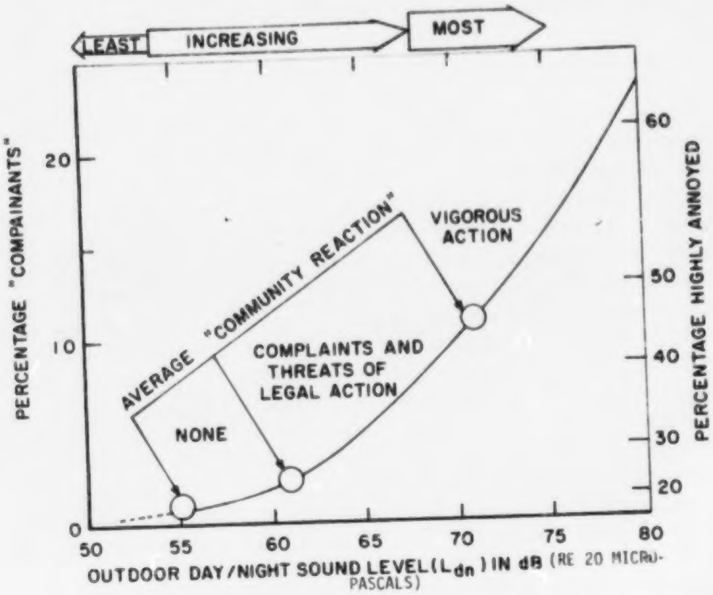
The relationships among percent complainants and percent highly annoyed (Figure D-14) together with the combined results of the two Heathrow surveys and the Tracor survey (Figures D-10 and D-13) have been combined in Figure D-16 to produce a general summary relationship between day-night sound level, percent complainants and percent highly annoyed. Also included in the figure is a scale of the relative importance of aircraft noise as a factor in disliking an area or wanting to move (Figures D-11 and D-12) and the average values of the three main community noise reaction categories (Figure D-7).

The results indicate that below an outdoor day-night sound level of 55 dB, less than 1% of the households would be expected to complain, although 17% of the people may respond as highly annoyed when questioned in a social survey. "No reaction" would be expected in the average community, and noise would be the least important factor in attitude towards neighborhood. When the outdoor L_{dn} is 60 dB, approximately 2% of the households might be expected to complain, although 23% of the people may respond as highly annoyed when questioned, and some reaction would be expected from an average community. If the levels increase over 65 dB, more than 5% may be expected to complain, and over 33% would respond as highly annoyed. Increasingly, vigorous community reaction could be expected, and noise becomes the dominant factor in disliking an area.

Table D-9

PERCENTAGE OF PEOPLE
WHO WERE EVER DISTURBED BY NOISE AT HOME,
OUTDOORS AND AT WORK IN LONDON CITY SURVEY[D-18]

	At Home	Outside	At Work
Disturbed from time to time	56	27	20
Notice but not disturbed	41	64	70
Do not notice	3	9	10



Relative Importance of Aircraft As A Factor in Disliking Area or Wanting to Move (Heathrow 1st Study) D-7, D-10, D-11, D-12 and D-13

Figure D-16. Summary of Annoyance Survey and Community Reaction Results

It is important to keep in mind that the annoyance/tolerance limits obtained from the social survey results have been found to be based on relatively well defined health and welfare criteria: the disturbance of essential daily activities.[D-19]

VARIOUS PRIOR RECOMMENDATIONS FOR ACCEPTABLE SOUND LEVELS

Recommended values for acceptable sound levels in various types of spaces have been suggested by a number of authors over the past two decades. These recommendations generally have taken into consideration such factors as speech intelligibility and subjective judgements by space occupants. However, the final values recommended were largely the result of judgements on the part of the authors, which in the case of acoustical consultants, have been motivated by the need for design values which will be on the "safe" side. One of the earliest publications providing recommended values in modern terminology was that of Knudsen and Harris[D-21] in 1950. It is of interest to quote from the text to understand the reasoning used to develop the recommended levels:

> Acceptable Noise Levels in Buildings
>
> The highest level of noise within a building that neither disturbs its occupants nor impairs its acoustics is called the acceptable noise level. It depends, to a large extent, on the nature of the noise and on the type and customary use of the building. The time fluctuation of the noise is one of the most important factors in determining its tolerability. For example, a bedroom with an average noise level of 35 dB, with no instantaneous peak levels substantially higher, would be much more conducive to sleep than would be a room with an average noise level of only 25 dB but in which the stillness is pierced by an occasional shriek. Furthermore, levels that are annoying to one person are unnoticed by another. It is therefore impossible to specify precise values within which the noise levels should fall in order to be acceptable. It is useful, however, to know the range of average noise levels that are acceptable under average conditions. A compilation of such levels for various types of rooms in which noise conditions are likely to be a significant problem is given in [Table D-10.*] The recommended acceptable noise levels in this table are empirical values based on the experience of the authors and others they have consulted. Local conditions or cost considerations may make it impractical to meet the high standards inherent in these relatively low noise levels. In more than 80 percent of the rooms of some of the types listed, the prevalent average noise levels exceed the recommended acceptable levels. However, it should be understood that the acceptance of higher noise levels incurs a risk of impaired acoustics or of the comfort of the individuals in the room.

Since 1950 recommendations by a number of authors, as well as national standards, have been presented. Eighteen of these recommendations are tabulated in Table D-10.[D-21 through D-38] It is encouraging to note the consistency displayed, although many of the later recommendations may be based on the recommendations of the earlier authors.

SUMMARY OF NOISE INTERFERENCE WITH HUMAN ACTIVITIES AND RESULTING HEALTH/WELFARE EFFECTS

The primary effect of noise on human health and welfare due to interference with activity comes from its effect on speech communication.

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*These values are given in the first column of Table D-10.

Table D-10

PRIOR RECOMMENDATIONS OF SOUND LEVELS IN VARIOUS SPACES[D-21 through D-38]

B&M
August 10, 1973
RECOMMENDED ACCEPTABLE NOISE LEVELS

	Knudsen-Harris 1950 1 db(A)	Beranek 1953 2 dB(A)^{c}	Beranek 1957 3 dB(A)	Lawrence 1962 4 dB(A)	Kosten-Van Os 1962 5 dB(A)^{c}	Ashrae 1967 6 dB(A)*	Dennow 1970 7 dB(A)	Kryter 1970 8 dB(A)	Tokyo 1971 9 dB(A)	USSR 1971 10 dB(A)	Beranek 1971 11 dB(A)	Doelle 1972 12 dB(A)^{c}	Wood 1972 13 dB(A)^{c}	Rettinger 1973 14 dB(A)	Sweden (p-9) 15 dB(A)	Switzerland 1970 (p-4) 16 dB(A)	Czechoslovakia 1967 (p-10-11) 17 dB(A)	West Germany 1968 (p-12) 18 L_{eq} M-D
RESIDENT																		
Home																		
Bedroom	35-45	35	35-45	25	30	25-35		40		35	34-47	35-45	35	34-42	25	35-45	40	
Living Room	35-45	35		40	35	30-40		40		35	38-47		40		25	35-45	40	
Apartment	35-45		35-40	30		35-45		18			34-47			38-42		35-50	40	
Hotel	35-45		35-40	35-40		35-45		38		35	34-47	35-54	30-40	42		35-50	40	
COMMERCIAL																		
Restaurant	50-55	55	55	40-60	50	40-55		55		55	42-52	45-60	45-50	50		40-50	55	
Private Office	40-45	50	30-45	35-45	30-45	25-45	40-45	35			38-47	30-45	40-45	46	40			
General Office	45-55		40-55	40-60	60	35-65	50-60	35-40		50	42-52	45-55	45-55	50				
Transport						35-55				60								
INDUSTRIAL																		
Workshop																		
Light		50		40-60							52-61		55-65			45-55		
Heavy		75		60-90	70		85				66-80		60-75	70		50-60		
EDUCATION																		
Classroom	35-40	35	35	30-40	30	35-45		35		40	38-47	35	35-45	38	35	35-45		
Laboratory				40-50		40-50	40-50				47-46		45-50	42				
Library	40-45	40	42-45	35-45	35	35-45		40			38-47	40-45	40-45	42			40	
HEALTH																		
Hospital	35-40	40	42	20-35	35	30-45		40		25	34-47	40	40-45	38	25-35	25-35	35-40	
RECREATION																		
Swimpool						45-60							50-60	50				
Sports (ampl.)		60	30			35-45				60		60		46			60	
Gymnasium					55	40-50						55-60	45-55	46				
AUDITORIUM																		
Assembly Hall	35-40	35	35-40	40-45		30-40		38			30-42	35-45	35-45					
Church	35-40	40	40	35-40	35	25-35		40		35	30-42	35-40	35-40	38-42				
Concert Hall	30-35	30-35	25-35	25-35	30	25-35		28-35			21-30	25-35	30-35	34			35	
Court Room	40-45	40	40-45	40-45	35			40			42	35-40	35-40					
Record Studio	25-30	30	25-30	20-30	20	25-35		28			21-34	25-30	30	30				
TV Studio	25-30	30	30	25-35	30	25-35		28			21-34	30-35	35	34-38				
Mot. Pict. Studio	25-30	30	25-30		25-35			28			21-34	35	25					
Mot. Pict. Theater	35-40	40	40		35	35-45		40		40		40	35-40	38				
Lec. Theater	30-35	35	30-35		25	30-40		33			30-34	30-35		34			35	
OUTSIDE																		
Rural									35-45	35								35-45
Suburb									40-50	45								35-50
Urban									50-60									40-55
Industrial									50-60									50-65
Res Areas															55			
Near Schools																		
Hospitals																		

Note db(A)^{c} = MC = 10
*6 dB greater than AHSRAE'S cited MC

The levels that interfere with human activities which do not involve active listening cannot be quantified relative to the level of a desired sound. Rather, the level of an intruding sound that will cause an interference depends upon its relation to the level of the other background sounds in the environment and the state of the human auditor, e.g., the degree of concentration when endeavoring to accomplish a mental task, or the depth of sleep, etc.

The levels of environmental noise that are associated with annoyance depend upon local conditions and attitudes. They cannot be clearly identified in terms of the national public health and welfare. The only levels which can be so identified are the levels which are required to assure that speech communication in the home and outdoors is adequate in terms of public health and welfare. Lower levels may be desirable and appropriate for specific local situations.

The level identified for the protection of speech communication is 45 dB within the home. Allowing for the 15 dB reduction in sound level between outdoors and indoors, this level becomes an outdoor day-night sound level of 60 dB (re 20 micropascals) for residential areas. For outdoor voice communication, the outdoor day-night level of 60 dB allows normal conversation at distances up to 2 meters with 95% sentence intelligibility.

Although speech interference has been identified as the primary interference of noise with human activities, and as one of the primary reasons for adverse community reactions to noise and long-term annoyance, a margin of safety of 5 dB is applied to the maximum outdoor level to give adequate weight to all of these other adverse effects.

Therefore, the outdoor day-night sound level identified for residential areas is a day-night sound level of 55 dB.

The associated interior day-night sound level within a typical home which results from outdoors is 15 dB less, or 40 dB. The expected indoor daytime level for a typical neighborhood which has an outdoor day-night sound level of 55 dB is approximately 40 dB, whereas the nighttime level is approximately 32 dB (see Figure A-7). This latter value is consistent with the limited available sleep criteria.[D-5] Additionally, these resulting indoor levels are consistent with the background levels inside the home and which have been recommended by acoustical consultants as "acceptable" for many years (Table D-10).

The effects associated with an outdoor day-night sound level of 55 dB are summarized in Table D-11. The summary shows:

1. Satisfactory outdoor average sentence intelligibility may be expected for normal voice conversations over distances of up to 3.5 meters;

Table D-11

SUMMARY OF HUMAN EFFECTS IN TERMS OF SPEECH COMMUNICATION, COMMUNITY REACTION, COMPLAINTS, ANNOYANCE AND ATTITUDE TOWARDS AREA ASSOCIATED WITH AN OUTDOOR DAY/NIGHT SOUND LEVEL OF 55 dB re 20 MICROPASCALS

Type of Effect	Magnitude of Effect
Speech – Indoors	100% sentence intelligibility (average) with a 5 dB margin of safety
– Outdoors	100% sentence intelligibility (average) at 0.35 meters 99% sentence intelligibility (average) at 1.0 meters 95% sentence intelligibility (average) at 3.5 meters
Average Community Reaction	None, 7 dB below level of significant "complaints and threats of legal action" and at least 16 dB below "vigorous action" (attitudes and other non-level related factors may affect this result)
Complaints	1% dependent on attitude and other non-level related factors
Annoyance	17% dependent on attitude and other non-acoustical factors
Attitudes Toward Area	Noise essentially least important of various factors

2. Depending on attitude and other non-acoustical factors, the average expected community reaction is "none" although 1% may complain and 17% indicate "highly annoyed" when responding to social survey questions; and

3. Noise is the least important factor governing attitude towards the area.

Identification of a level which is 5 dB higher than the 55 dB identified above would significantly increase the severity of the average community reaction, as well as the expected percentage of complaints and annoyance. Conversely, identification of a level 5 dB lower than the 55 dB identified above would reduce the indoor levels resulting from outdoor noise well below the normal background indoors. It would decrease speech privacy outdoors to marginal distance. Little change in annoyance would be made since at levels below the identified level, individual attitude and life style, as well as local conditions, are more important factors in controlling the resulting magnitude of the level of the intruding noise.

In conclusion, a L_{dn} level of 55 dB is identified as outdoor level in residential areas compatible with the protection of public health and welfare. The level of 55 dB is identified as maximum level compatible with adequate speech communication indoors and outdoors. With respect to complaints and long term annoyance this level is clearly a maximum satisfying the large majority of the population (see Table D-11). However, specific local situations, attitudes, and conditions may make lower levels desirable for some locations. A noise environment not annoying some percentage of the population cannot be identified at the present time by specifying noise level alone.

REFERENCES FOR APPENDIX D

D-1 "Effects of Noise on People," Environmental Protection Agency, NTID 300.7, December 1971.

D-2 Webster, J. C., "Effects of Noise on Speech Intelligibility", Noise as a Public Health Hazard, American Speech and Hearing Association, No. 4, February 1969.

D-3 Eldred, K. M., "Community Noise," Environmental Protection Agency NTID 300.3, December 1971.

D-4 "Method for the Calculation of the Articulation Index," American National Standards Institute, ANSI 53.5-1969, New York.

D-5 "Public Health and Welfare Criteria for Noise," Environmental Protection Agency, 550/9-73-002, July 27, 1973.

D-6 "Noise-Final Report," H.M.S.O., Cmnd. 2056, London, July 1963.

D-7 Connor, W. K. and Patterson, H. P., "Community Reaction to Aircraft Noise Around Smaller City Airports", NASA CR-2104, August 1972.

D-8 Bitter, C., "Noise Nuisance Due to Aircraft," Institut Vour Gezondheidstechniek TNO, 1968.

D-9 Bolt Beranek and Newman, Inc., "Survey of Annoyance from Motor Vehicle Noise," Automobile Manufacturers Association, Inc., Report 2112, June 1971.

D-10 Rosenblith, W. A., Stevens, K. N., and the Staff of Bolt Beranek and Newman, Inc., "Noise and Man," *Handbook of Acoustic Noise Control,* Vol. 2, WADC TR-52-204, Wright-Patterson Air Force Base, Ohio: Wright Air Development Center, 1953.

D-11 Stevens, K. N., Rosenblith, W. A., and Bolt, R. H., "A Comminity's Reaction to Noise: Can It Be Forecast?" *Noise Control,* 1:63-71, 1955.

D-12 Stevens, K. N., and Baruch, J. J., "Community Noise and City Planning," *Handbook of Noise Control,* Chapter 35, McGraw-Hill Book Co., 1957.

D-13 Parrack, H. O., "Community Reaction to Noise," *Handbook of Noise Control,* Chapter 36, McGraw-Hill Book Co., 1957.

D-14 Stevens, K. N. and Pietrasanta, A. C., and the Staff of Bolt Beranek and Newman, Inc., "Procedures for Estimating Noise Exposure and Resulting Community Reactions from Air Base Operation," WADC TN-57-10, Wright-Patterson Air Force Base, Ohio: Wright Air Development Center, 1957.

D-15 "Second Survey of Aircraft Noise Annoyance Around London (Heathrow) Airport," H.M.S.O., London, 1971.

D-16 Bitter, C., "Noise Nuisance Due to Aircraft," Collogue sur la definition des exigences humain a l'egard du bruit, Paris, November 1968.

D-17 Borsky, P. N., "A New Field-Laboratory Methodology for Assessing Human Response to Noise," NASA CR-2221, March 1973.

D-18 "Noise in Towns," *NOISE,* Chapter IV, 22-31, Presented to Parliament by the Lord President of the Council and Minister for Science by Committee on the Problem of Noise, July 1963; H.M.S.O., London, Reprinted 1966.

D-19 "Safeer, Harvey B., "Community Response to Noise Relative to Percent of Population Highly Annoyed by Noise," US Department of Transportation, Office of Noise Abatement TM 72-1, June 6, 1972.

D-20 "Social and Economic Impact of Aircraft Noise," Sector Group on the Urban Environment, Organization for Economic Co-Operation and Development, April 1973.

D-21 Knudsen, E. O. and Harris, C. M., *Acoustical Designing in Architecture,* New York: J. Wiley and Sons, 1950.

D-22 Beranek, L., Reynolds, J. L., and Wilson, K. E., "Apparatus and Procedures for Predicting Ventilation System Noise," JASA, v. 25, no. 2: 313, 1953.

D-23 Beranek, L., "Revised Criteria for Noise in Buildings," *Noise Control,* v. 3, no. 1, 1957.

D-24 Lawrence, A., *Acoustics in Buildings,* Australian Building Science Series 1, p 70, 1962.

D-25 Kosten, C. W. and van Os., G. J., "Community Reaction Criteria for External Noises," National Physical Laboratory Symposium No. 12, London, H.M.S.O. 1962.

D-26 ASHRAE; *Guide and Data Book, Systems and Equipment,* American Society of Heating, Refrigerating and Air Conditioning Engineers, p 379, 1967.

D-27 Denisov, E. I., "New Health Norms on Noise", Institut Gigiyeny Truda i Profzabolevaniy AMN SSSR, Moscow, v. 14, no. 5:47, 1970.

D-28 Kryter, K., *The Effects of Noise on Man,* Academic Press, p 459, 1970.

D-29 "Noises in Tokyo", Report on the Tokyo Conference on Environmental Protection, November 8-11, 1971.

D-30 "Sanitary Norms for Permissible Noise in Living Quarters and Public Buildings and in Residential Construction Areas," Main Sanitary-Epidemiological Administration, USSR, 1971.

D-31 Beranek, L., *Noise and Vibration Control,* p 585, McGraw-Hill, 1971.

D-32 Doelle, L., *Environmental Acoustics,* p 186, McGraw-Hill, 1972.

D-33 Woods, R. I., "Noise Control in Mechanical Services," Published jointly by Sound Attenuators Ltd and Sound Research Laboratories Ltd, 1972.

D-34 Rettinger, M., *Acoustic Design and Noise Control,* New York: p 158, Chemical Publ. Co., Inc., 1973.

D-35 Sweden National Board of Urban Planning, Samhallsplannering och Vagtrafikbuller, Stockholm: 1971.

D-36 Schweizerischer Ingenieur - und Architekten - Verein, Empfehlung fuer Schallschutz im Wohnnungsbau, SIA No. 181, Zuerich, 1970.

D-37 The Czech Ministry of Health; Richtlinien fuer Gesundheitsschutz gegen unguenstige Wirkung von Laerm; Vorschriften der Hygiene, Band 28, 1967, Prague: Staatsverlag fuer Medizinische Literatur 1967.

D-38 Der Bundesminister des Innen, Inventar der in der Bundesrepublik Deutschland geltenden oder geplanten Rechts-und Verwaltungsvorschriften ueber die Laermbekaempfung. Bonn April 30, 1973.

D-39 "Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure." EPA Document NTID 73.4, July 27, 1973.

Appendix E

GENERAL EFFECTS OF NOISE NOT DIRECTLY USED IN IDENTIFYING LEVELS OF NOISE REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE

Appendix E

GENERAL EFFECTS OF NOISE NOT DIRECTLY USED IN IDENTIFYING LEVELS OF NOISE REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE

There are a multitude of adverse effects that can be caused by noise which may, both directly or indirectly, affect public health and welfare. However, there are only three categories of adverse relationships in which the cause/effect relationships are adequately known and can be justifiably used to identify levels of environmental noise for protection of public health and welfare. These are: (1) the effect of noise on hearing, (2) the effect of noise on the general mental state as evidenced by annoyance, and (3) the interference of noise with specific activities. These three categories of effects, discussed in detail in Appendices C and D, will serve as the main basis for identifying the levels in Section 3 of this document.

Since a causal link between community noise and extra-auditory disease has not been established, this document proceeds on the assumption that protection against noise-induced hearing loss is sufficient for protection against extra-auditory effects. However, the generation of most stress-related disorders is somewhat longer than that required for noise-induced hearing loss, and this time interval may have clouded a causal association. Noise of lesser amplitude than that traditionally identified for the protection of hearing causes regular and dependable physiological responses in humans. Similar noise-induced physiological changes in sensitive animals regularly leads to the development of stress-related disease. The implications of generalizing from these animal studies to humans is not clear. With the availability of new information concerning the role of noise as a stressor in the pathogenesis of stress-related disease, the levels identified in this document may require further review.

In the meantime, the question that is invariably asked is, "What is the significance of omitting all other physiological effects?"

In answer to this question, most experts agree that, at present, there is insufficient knowledge of the effect of noise on health except for noise-induced hearing loss, (defining health in the more restricted sense, as the absence of disease). In a recent review of this subject[E-1] it was concluded that: "if noise control sufficient to protect persons from ear damage and hearing loss were instituted, then it is highly *unlikely* that the noises of lower level and duration resulting from this effort could directly induce non-auditory disease." Therefore, in this document, hearing loss will be considered the controlling effect.

This is not to say that there are no indications to arouse concern in the area of non-auditory effects, but substantial further research on these effects of noise on health would be required to alter the above statements. Such research should be fostered, and the results should be carefully monitored for any evidence indicating that the maximum sound levels identified herein are excessive.

Although noise can affect people indirectly by disturbing the general environment in which they live, the noise levels required to produce significant non-auditory physiological effects are normally much higher than the levels required to protect the public health and welfare from adverse effects on hearing or interference with activities.

However, for special conditions, certain effects which have not been directly utilized in identifying the levels in this document, should be examined. For this purpose, certain of the summary paragraphs of the EPA criteria document "Public Health and Welfare Criteria for Noise"[E-2] are included in this appendix. Caution must be exercised when using such information since, in many cases, there is no way to relate the exact exposure level to the effect in question.

EFFECTS OF NOISE ON HUMANS

Performance and Work Efficiency

Continuous noise levels above 90 dBA appear to have potentially detrimental effects on human performance, especially on what have been described as noise-sensitive tasks such as vigilance tasks, information-gathering and analytical processes. Effects of noise on routine-type tasks appear to be much less important, although cumulative degrading effects have been demonstrated by researchers. Noise levels of less than 90 dBA can be disruptive, especially if they have predominantly high frequency components, are intermittent, unexpected, or uncontrollable. The amount of disruption is highly dependent on:

- The type of task.
- The state of the human organism.
- The state of morale and motivation.

Noise does not usually influence the overall rate of work, but high levels of noise may increase the variability of the work rate. There may be "noise pauses" or gaps in response, sometimes followed by compensating increases in work rate. Noise is more likely to reduce the accuracy of work than to reduce the total quantity of work. Complex or demanding tasks are more likely to be adversely affected than are simple tasks. Since laboratory studies represent idealized situations, there is a pressing need for field studies in real-life conditions.

Although these possibly adverse effects were not used in identifying the noise levels in this document, employers or educational authorities should consider their influence since it might provide additional motivation to achieve the values seen in Table D-10 of Appendix D.

Effects of Noise on the Autonomic Nervous System and Other Non-Auditory Physiological Effects

Noise can elicit many different physiological responses. However, no clear evidence exists to indicate that the continued activation of these responses leads to irreversible changes and permanent health problems. Sound of sufficient intensity can cause pain to the auditory system, however, such intense exposures are rarely encountered in the non-occupational environment. Noise can also affect one's equilibrium, but the scarce data available indicates that the intensities required to do so must be quite high, similar to the intensities that produce pain.

Noise-induced orienting reflexes serve to locate the source of a sudden sound and, in combination with the startle reflex, prepare the individual to take appropriate action in the event of danger. Apart from possibly increasing the chance of an accident in some situations, there are no clear indications that the effects are harmful since these effects are of short duration and do not cause long-term physiological changes.

Noise can definitely interfere with sleep, however, relating noise-exposure level to the quality of sleep is difficult. Even noise of moderate levels can change the pattern of sleep, but the significance of these changes is still an open question.

Noise exposure may cause fatigue, irritability, or insomnia in some individuals, but the quantitative evidence in this regard is also unclear. No firm relationships between noise and these factors can be established at this time.

Interaction of Noise and Other Conditions or Influences

Determination of how various agents or conditions interact with noise in producing a given effect requires three separate determinations: the effect produced by the noise alone, the effect produced by the other agent alone, and the effect produced by the combined action of the agent and the noise. These results indicate whether the combined effect is indifferent, additive, synergistic, or ameliorative.

Chemical agents may have a harmful effect when combined with noise. Ototoxic drugs that are known to be damaging to the hearing mechanism can be assumed to produce at least an additive effect on hearing when combined with noise exposure. There are instances in which individuals using medication temporarily suffer a hearing loss when exposed to noise, but there is no definitive data on the interaction of ototoxic drugs and noise on humans. Evidence linking hearing loss with the combination of noise and industrial chemicals is also inconclusive.

The possibility of a synergistic effect exists when noise and vibration occur together. Vibration is usually more potent than noise in affecting physiological parameters. There appears to be consensus that vibration increases the effect of noise on hearing, but such increases are probably quite small.

Health disorders may interact with noise to produce a hearing loss. Mineral and vitamin deficiencies are one example but little research has been done on the effect of such deficiencies on susceptibility to noise. A reasonable hypothesis is that illness increases an individual's susceptibility to the adverse effects of noise. However, as with the other hypotheses, conclusive evidence is lacking.

Noise exposure can be presumed to cause general stress by itself or in conjunction with other stressors. Neither the relationship between noise exposure and stress nor the noise level or duration at which stress may appear have been resolved.

Exposure to moderate intensities of noise that are likely to be found in the environment may affect the cardiovascular system in various ways, but no definite permanent effects on the circulatory system have been demonstrated. Noise of moderate intensity has been found to cause vasoconstriction of the peripheral blood vessels and pupillary dilation. There is no evidence that these reactions to noisy environments can lead to harmful consequences over prolonged periods of noise exposure. However, speculation that noise might be a contributing factor to circulatory difficulties and heat disease is not yet supported by scientific data.

EFFECTS OF NOISE ON WILDLIFE AND OTHER ANIMALS

Noise produces the same general types of effects on animals as it does on humans, namely: hearing loss, masking of communications, behavioral, and non-auditory physiological effects.

The most observable effects of noise on farm and wild animals seem to be behavioral. Clearly, noise of sufficient intensity or noise of aversive character can disrupt normal patterns of animal existence. Exploratory behavior can be curtailed, avoidance behavior can limit access to food and shelter, and breeding habits can be disrupted. Hearing loss and the masking of auditory signals can further complicate an animal's efforts to recognize its young, detect and locate prey, and evade predators. Competition for food and space in an "ecological niche" results in complex interrelationships and, hence, a complex balance.

Many laboratory studies have indicated temporary and permanent noise-induced threshold shifts. However, damage-risk criteria for various species have not yet been developed. Masking of auditory signals has been demonstrated by commercial jamming signals, which are amplitude and frequency modulated.

Physiological effects of noise exposure, such as changes in blood pressure and chemistry, hormonal balance and reproductivity have been demonstrated in laboratory animals and, to some extent, in farm animals. But these effects are understandably difficult to assess in wildlife. Also, the amount of physiological and behavioral adaptation that occurs in response to noise stimuli is as yet unknown.

Considerable research needs to be accomplished before more definitive criteria can be developed. The basic needs are:

- More thorough investigations to determine the point at which various species incur hearing loss.
- Studies to determine the effects on animals on low-level, chronic noise exposures.
- Comprehensive studies on the effects on animals in their natural habitats. Such variables as the extent of aversive reactions, physiological changes, and predator-prey relationships should be examined.

Until more information exists, judgments of environmental impact must be based on the existing information, however incomplete. The most simple approach is to assume that animals will be at least partially protected by application of maximum levels identified for human exposure.

EFFECT OF NOISE ON STRUCTURES

Airborne sound normally encountered in real life does not usually carry sufficient energy to cause damage to most structures. The major exceptions to this are sonic booms produced by supersonic aircraft, low frequency sound produced by rocket engines and some construction equipment, and sonic fatigue.

From an environmental point of view, the most significant effects are those caused by sonic booms on the secondary components of structures. These effects include the breaking of windows and cracking of plaster. Effects such as these have led to the speculation that historical monuments and archeological structures may age more rapidly when exposed to repeated sonic booms. However, the levels identified in Appendix G to protect against adverse effects on public health and welfare are low enough to protect against damage to structures.

REFERENCES FOR APPENDIX E

E-1. "Effect of Noise on People," Environmental Protection Agency, NTID 300.7, December 1971.

E-2. "Public Health and Welfare Criteria for Noise," Environmental Protection Agency, 550/9-73-002, July 27, 1973.

Appendix F

EPA's RESPONSIBILITY TO IDENTIFY SAFE LEVELS FOR OCCUPATIONAL NOISE EXPOSURE

Appendix F

EPA's RESPONSIBILITY TO IDENTIFY SAFE LEVELS FOR OCCUPATIONAL NOISE EXPOSURE

Although the workplace is a vital component of the human environment, the Environmental Protection Agency does not have jurisdiction over most occupational health and safety matters. These matters have traditionally been the responsibility of the Departments of Labor and Health, Education and Welfare. Section 6(b)(5) of the Occupational Safety and Health Act of 1972 specifies that the Secretary of Labor, ". . . in promulgating standards dealing with toxic materials or harmful physical agents . . ., shall set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life . . . In addition to the attainment of the highest degree of health and safety protection for the employee, other considerations shall be the latest available scientific data in the field, the feasibility of the standards, and experience gained under this and other health and safety laws."

In contrast, section 5(a)(2) of the Noise Control Act of 1972 directs EPA's Administrator to "publish information on the levels of environmental noise, the attainment and maintenance of which in defined areas under various conditions are requisite to protecting the public health and welfare with an adequate margin of safety."

The words "public health and welfare" appear in a number of places in the Noise Control Act, and have a broader reference than those defining jurisdiction in the Occupational Safety and Health Act, namely, the entire American public at all times rather than the American worker during his workday. In addition, the requirement of an "adequate margin of safety" does not appear in the Occupational Safety and Health Act, which instead uses the phrase, "no employee will suffer material impairment of health or functional capacity." These distinctions indicate that EPA's duty to identify levels for exposure to noise is broader in scope and more stringent that OSHA's duty to protect in the occupational area. Furthermore, the intent of this document is to identify safe levels for a variety of settings, whereas the responsibility of HEW is to develop occupational exposure criteria and that of the Department of Labor is to promulgate and enforce standards. In the writing of such standards, the Labor Department must take feasibility into account, a consideration omitted in the writing of this document.

EPA's responsibility to identify levels of exposure to noise "in defined areas under various conditions" necessarily includes an identification of exposure levels in the workplace in order to satisfy the intent of the law to consider total human exposure to noise. Working hours are an inseparable part of the individual's 24-hour day, and they must be considered in order to evaluate the contributions of nonoccupational exposure to his daily and lifetime dose. For this reason, it is of utmost importance that the levels specified for occupational and non-occupational noise be compatible.

Appendix G

IMPULSE NOISE AND SOME OTHER SPECIAL NOISES

Appendix G

IMPULSE NOISE AND SOME OTHER SPECIAL NOISES

IMPULSE NOISE

Impulse noise is defined in various ways [G-1, G-2, G-11] but generally means a discrete noise (or a series of such noises) of short duration (less than a second), in which the sound pressure level rises very rapidly (less than 500 ms, sometimes less than 1 ms) to a high peak level before decaying below the level of background noise. The decay is frequently oscillatory, because of sound reflections and reverberation (ringing) in which case the spectrum of the oscillation may also be important in determining the hazard to hearing. Some authors distinguish reverberant impulse noise as "impact" noise (typically produced by metal to metal impact as in industrial forging), to distinguish it from simple oligophasic impulses (typified by a gunshot in the open air).[G-3]

The peak sound pressure level (SPL) is an important but not the sole parameter determining hazard. Some typical values for disturbing or hazardous impulse noises are given in Table G-1.

NOTE: Peak SPL for impulses cannot be properly measured with a standard sound level meter, which is a time-averaging device. Oscillographic techniques must be used.

Table G-1

SOME TYPICAL VALUES OF PEAK SPL FOR IMPULSE NOISE
(in dB re 20 micropascals)

SPL	EXAMPLE
190+	Within blast zone of exploding bomb
160-180	Within crew area of heavy artillery piece or naval gun when shooting
140-170	At shooter's ear when firing hand gun
125-160	At child's ear when detonating toy cap or firecracker
120-140	Metal to metal impacts in many industrial processes (e.g., drop-forging; metal-beating)
110-130	On construction site during pile-driving

Effects of Impulse Noise on People

Cochlear Damage and Hearing Loss

Impulse noise can produce temporary (TTS) and permanent threshold shift (PTS). The pattern essentially resembles that produced by a continuous noise but may involve somewhat higher frequency losses (maximal at 4 to 6 kHz) and recovery from impulse-NIPTS can be more variable.[G-9] A blow to the head can have a similar effect. TSS (and, by inference, PTS) in man depends on many factors, the more important of which are reviewed in more detail later. Impulse noise (like continuous noise) can also be shown to produce pathological changes in the inner ear (cochlea) of mammals, notably destruction and degeneration of the haircells of the hearing organ, and atrophic changes in related structures. A quantitative relationship between the amount of visible damage to the cochlea and the amount of NIPTS has not yet been clearly established.[G-2, G-4, G-5]

Other Pathological Effects

Exposure to blast or to sustained or repeated impulsive airborne over-pressures in the range of 140 to 150 dB (239 to 718 pascals) or higher can cause generalized disturbance or damage to the body apart from the ear. This is normally a problem for military personnel at war (e.g., artillerymen firing field guns), and need not be considered further here. Transient over-pressures of considerable magnitude can be experienced due to sonic boom but are unlikely to be hazardous to the ear.

Startle and Awakening

Impulsive noises which are novel, unheralded, or unexpectedly loud can startle people and animals. Even very mild impulsive noises can awaken sleepers. In some circumstances (e.g., when a person is handling delicate or dangerous objects or materials), startle can be hazardous. Because startle and alerting responses depend very largely upon individual circumstances and psychological factors unrelated to the intensity of the sound, it is difficult to make any generalization about acceptable values of SPL in this connection. A high degree of behavioral habituation, even to intense impulse noises such as gunfire, is normally seen in animals and humans when the exposure is repeated, provided that the character of the stimulus is not changed.

Parameters of Impulse Noise Exposure

Impulse noise is characterized completely by the waveform and spectrum. Various summary parameters are also useful in characterizing an impulsive noise, these include:

1. Peak SPL (in dB re 20 micropascals)
2. Effective duration (in milliseconds or microseconds)
3. Rise time

In addition, the following are important for predicting the effects of the impulse on people:

4. Number of repeated impulses in a daily or other cumulative exposure
5. Intervals or average interval between repeated impulses (or rate of impulse occurrence)
6. Individual susceptibility to inner ear damage
7. Orientation of the ear with respect to the noise
8. Preceding or simultaneous exposure to continuous noise at TTS-producing levels
9. Action of acoustic reflex, if elicited
10. Audiometric frequency

Impulse Noise Exposure Criteria and Limits

Hearing Damage and Criteria for Impulse Noise

It is obvious from the above lists that limiting impulse noise exposure for hearing conservation is not an easy matter. Existing guidance in this matter in some spheres is seriously inadequate or misleading.[G-3] For instance, the Occupational Safety and Health Act prescribes a limiting level of 140 dB SPL for industrial impulse noise, with no allowance for any other parameter.

In 1968, Working Group 57 of CHABA prepared a damage risk criterion for gunfire noise, based essentially on the work of Coles *et. al.*,[G-6] which included procedures to allow for repetition of impulses and some of the other parameters listed above.[G-1] Some modification has recently been proposed by Coles and Rice.[G-7] The CHABA proposal was intended to protect 95% of the exposed population.

Guidelines for Evaluating Hazard from Impulse Noise Exposure

Peak Level

The growth of TTS at 4 kHz with increase in peak level above 130 dB SPL of impulses (clicks) presented at a steady rate has been demonstrated by Ward *et. al.*[G-8] Based on TTS data from rifle shooters, Kryter and Garinther[G-18] estimated permanent hearing levels expected to result from daily exposure to a nominal 100 rounds of rifle shooting noise in selected percentiles. Their data are reproduced in Table G-2 below, showing the increasing hazard with increasing peak level and with increasing audiometric frequency up to 6000 Hz.

CHABA's 1968 Damage-Risk Criteria (DRC)[G-1] recommended limits to peak level as a function of impulse duration for a nominal exposure of 100 impulses per day at normal incidence (discussed below and shown in Figure G-1). These limits were intended to protect 95% of the people according to an implied criterion of NIPTS not exceeding 20 dB at 3 kHz or above, after 20 yrs. If 90% of the people were to be protected to a criterion of NIPTS not exceeding 5 dB at 4 kHz, it would be necessary to lower the CHABA limits by 12 dB (15 dB reduction to meet the more stringent criterion, assuming an approximately decible to decibel relationship in the range of interest [see Table G-2], less 3 dB elevation to apply the limit to the 90th percentile). This modified CHABA limit is shown in Figure G-1 by hatched lines.

Duration of Impulse

Hazard increases with the effective duration of impulses.[G-10] Impulse duration is defined according to the type of impulse (A, simple peak, or B, oscillatory decay);[G-1, G-6] and CHABA has recommended separate limits for A- and B-durations (Figure G-1). For effective durations much above 1 ms, a more stringent limit should be applied to reverberant oscillations (e.g., metallic impacts in industry or gunshots in a reverberant indoor range) than to simple A-type impulses (e.g., gunshots in the open). When the type of impulse cannot be determined, it is conservative to assume the B-duration.

Table G-2

ESTIMATED EXPECTED PERMANENT HEARING LEVEL (IN DB RE ASA:1951) IN SELECTED PERCENTILES OF THE MOST SENSITIVE EARS FOLLOWING NOMINAL DAILY EXPOSURE TO RIFLE NOISE (DURING TYPICAL MILITARY SERVICE), NAMELY, 100 ROUNDS AT ABOUT 5 SECOND INTERVALS[G-18]

Peak SPL* (dB)	Percentile Exceeding HL	Audiometric Test Frequency (Hz)				
		1000	2000	3000	4000	6000
170	10	25	35	70	85	90
	25	15	25	55	65	70
	50	0	10	35	45	50
165	10	16	20	62	60	67
	25	9	10	32	45	52
	50	0	0	12	25	47
160	10	15	16	25	45	60
	25	7	8	18	35	45
	50	0	0	0	15	25
150	10	10	15	15	35	50
	25	3	4	8	25	40
	50	0	0	0	10	20
140	10	0	5	10	30	45
	25	0	2	2	18	30
	50	0	0	0	5	10

*At the ear, grazing incidence.

CHABA[G-1] 1968 warned that the 152 and 138 dB plateaux are only "gross estimates"· similar remarks apply to the modified CHABA limit here proposed, in which the corresponding plateaux are 140 and 126 dB SPL.

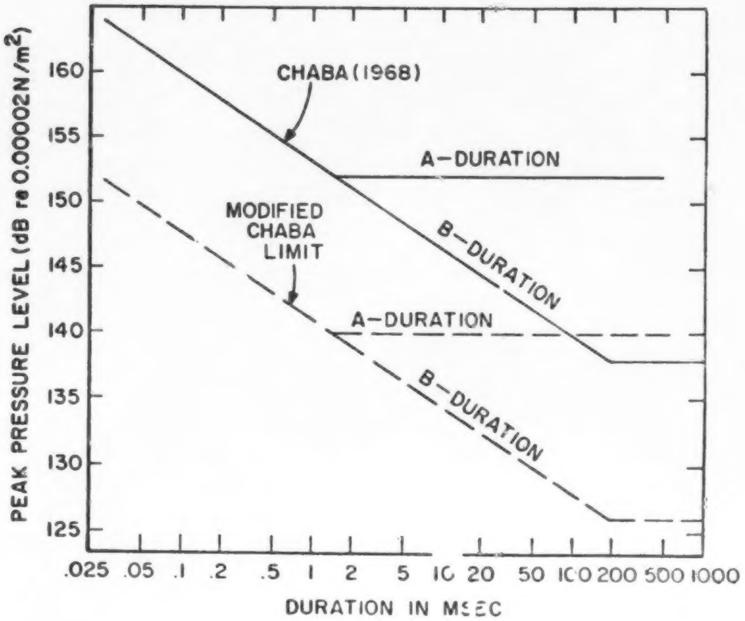

Figure G-1. The 1968 CHABA [G-1] Damage-Risk Criterion for Impulse Noise Exposure (solid lines) and a Proposed Modification (hatched lines). Peak Sound Pressure Level is Expressed as a Function of A- or B-Duration in the Range 25 Microseconds to 1 Second. [G-1]

Rise Time

This parameter is usually correlated closely with peak pressure. Present evidence as to its effect on hearing risk is insufficient for allowance to be made for it in damage risk criteria.

Spectrum (Or Waveform)

Impulses with largely high frequency spectral components (e.g., reverberant gunshots) are generally more hazardous to the hearing mechanism than predominantly low-frequency impulses (e.g., distance-degraded blast waves; sonic booms) of the same peak SPL. However, comparative data are as yet too scanty to serve as the basis of differential damage risk criteria.

Number of Repeated Impulses

TTS (and, by inference, NIPTS) grows linearly with the number of impulses in a series, or linearly with time when the rate of impulses is constant.[G-8] CHABA[G-1] recommended an allowance of -5 dB for every tenfold increase in number of impulses in a daily exposure (Figure G-2). Recently, Coles and Rice[G-7] have contended that this rule is underprotective for large numbers (N) of impulses and have recommended a modification (see Figure G-2). In 1973, McRobert and Ward [G-3] questioned this modification, maintaining that it is probably grossly overprotective for N>1000, and commented also on the CHABA rule in the light of recent experiments. Figure G-2 reproduces a comparison by McRobert and Ward of the CHABA rule with Coles and Rice[G-7] and an "equal-energy" rule (10 dB weighting for each tenfold increase in N) originating at N = 100.

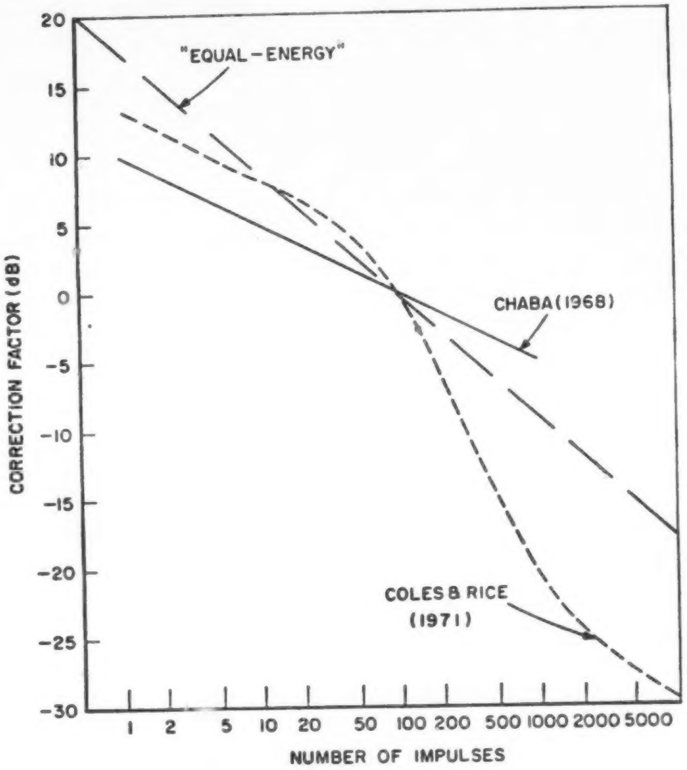

Figure G-2. Comparison of CHABA Weighting (Re: Zero at N = 100 Impulses per Day) for Number (N) of Impulses in Daily Exposure [G-1] with the Proposed Modification by Coles and Rice [G-7] and an "Equal-Energy" Rule. After McRoberts and Ward.[G-3]

All in all, an "equal-energy" rule appears to fit the existing data tolerably well and is easy to apply in practice, but it may underestimate the hazard for values of N substantially less than 100 (isolated impulses).

Interval Between or Rate of Occurrence of Impulses

Ward, *et. al*[G-8] showed that, when equal impulses occur at more than 1/s, TTS development is slower than when the average interval is in the range 1 to 9 s, presumably because the acoustic reflex is maintained. When the interval is long (range 9 - 30 seconds), TTS again develops more slowly, probably because the interval allows some recovery. A conservative rule would be to apply a 5 dB penalty when the average impulse interval lies between 1 and 10 seconds; such an interval may be typical of such activities as range shooting in groups, heavy hammering in industry, or pile-driving.

Individual Susceptibility to Inner Ear Damage

The distribution of individual susceptibility to NITTS and NIPTS in the population is believed to have the same pattern for impulse as for continuous noise. Similar rules may therefore be applied when predicting risk of impulse-NIPTS. The CHABA[G-1] DRC was intended to protect 95% of the population; a relaxation of 3 dB may be applied to obtain limits for the 90th percentile.

Orientation of the Ear

Based on Hodge & McCommons[G-12] and other data, CHABA[G-1] has recommended, in the case of gun noise, a penalty of 5 dB to apply when the noise strikes the eardrum at normal rather than grazing incidence. If uncertain, it is conservative to assume normal incidence.

Combinations of Impulse and Continuous Noise

Certain combinations of impulsive and continuous noise, such as occur in industry may be antagonistic–that is, one may provide some protection from the other–probably because of acoustic reflex activation. Other studies, however, show that the effects of combined impulse and steady noise are additive.[G-2,G-16] ISO, in its Recommendation R/1999,[G-17] proposed a flat weighting of 10 dB for "impulsiveness" in distributed noise, but the validity of this rule is questionable. On present evidence, it is probably safest to evaluate simultaneous impulsive and continuous noise separately, each according to its own criterion.

Action of the Acoustic Reflex

This protective mechanism is valueless in the case of brief single or isolated impulses because it has a latency of at least 10 ms and takes up to 200 ms before being fully effective. Rapidly repeated impulses,[G-7] however, or simultaneous continuous noise,[G-15] may activate it sufficiently to provide up to 10 dB of protection: but this is too variable and uncertain to be allowed for in damage risk criteria.

Audiometric Frequency

Generally speaking, impulse noise affects the hearing in much the same way as does continuous noise, with TTS and PTS beginning and growing most rapidly at 4 to 6 kHz. It is possible, however, that impulse noise may have relatively more effect on high-frequency hearing or affect hearing at higher frequencies.[G-13,G-14]

Use of Equivalent Continuous Sound Level (L_{eq}) In Evaluation of Impulse Noise

Support for the extension of the equal-energy (equivalent A-weighted sound energy) concept of hearing hazard from continuous noise exposure to include impulse noise exposure has recently been gaining ground.[G-19] At the 1970 Teddington Conference on "Occupational Hearing Loss", it was suggested that a unifying rule based on this concept might be drawn up to link continuous and impulse noise exposure limits in a single continuum relating A-weighted sound level to effective daily exposure duration.[G-20] An empirical formula enabling the A-weighted L_{eq} to be calculated from the peak sound pressure (p_h) repetition rate in impulses per second (N) and the decay constant of the impulse envelope (k) in inverse seconds, was introduced as follows:[G-21]

$$L_{eq} = 85.3 + 20 \log P_h + 10 \log N - 10 \log k + 10 \log (1-e^{-2/kN})$$

where p_h is absolute pressure in pascals; *not* sound pressure level in dB. For one impulse of the B-type, this formulation simplifies such that the L_{eq} of an A-weighted continuous pulse of duration T is equal to the peak sound pressure level (in dB) of an impulse which decays by 20 dB in time T minus 9 dB. The use of this formula assumes the impulse is composed of broad-band noise that exponentially decays. This relationship, at the present time, should not be used to evaluate impulse data until it is further justified by more experimental research. However, it does provide further support of the equal energy concept outlined in Appendix C.

Summary and Conclusions

Hearing Conservation

The following rules may be recommended if it is desired to protect 90% of the people from significant impulse-NIPTS, that is, from impulse-NIPTS exceeding 5 dB at 4 kHz after 10 years of repeated exposures:

1. Measure or predict the peak level (SPL) and A- or B-type duration of the impulse, using proper oscillographic technique (NOTE: if the noise is sufficiently rapidly repetitive to fit Coles and Rice's [G-7] category "C", it may be treated and measured as continuous noise and evaluated accordingly in dBA. This usually means a repetition rate exceeding 10/s).

2. Use the "modified CHABA limit" in Figure G-1 to determine the maximum permissible peak SPL. If in doubt as to impulse type, assume B-duration.

3. If the number of similar impulses (N) experienced per day exceeds 100, reduce the permissible level by 10 dB for every tenfold increase in N (e.g., 10 dB when N = 1000, 20 dB when N = 10,000).

4. If N is less than 100, a higher peak level may be allowed in accordance with the same rule (e.g., 10 dB more when N = 10), provided that an absolute maximum value of 167 dB for durations less than 25 microseconds, grazing incidence (or 162 dB normal incidence) is not exceeded.

5. If the average repetition rate of impulses falls in the range 0.1 to 1 per second (i.e., the average interval between impulses is 1 to 10 seconds), reduce the permissible peak level by 5 dB.

6. If the impulses are known to reach human ears in the vicinity at grazing incidence, the permissible peak level may be raised by 5 dB. NOTE: This allowance should be used with caution and must not be applied if the surroundings are reverberant. If in doubt, assume normal incidence.

Effects Other Than on Hearing

See Section 3 in main document.

SPECIAL NOISES

Infrasound[G-26]

Frequencies below 16 Hz are referred to as infrasonic frequencies. Sources of infrasonic frequencies include earthquakes, winds, thunder, and jet aircraft. Man-made infrasound occurs at higher intensity levels than those found in nature. Complaints associated with high levels of infrasound resemble mild stress reactions and bizarre auditory sensations, such as pulsating and fluttering. It does not appear, however, that exposure to infrasound, at intensitities below 130 dB SPL, present a serious health hazard. For the octave band centered at 16 Hz, the A-weighted equivalent to 130 dB SPL is 76 dB(A).

Ultrasound[G-26]

Ultrasonic frequencies are those above 20,000 Hz. They are produced by a variety of industrial equipment and jet engines. The effects of exposure to high intensity ultrasound (above 105 dB SPL) are also the effects observed during stress. However, there are experimental difficulties in assessing the effects of ultrasound since:

1. Ultrasonic waves are highly absorbed by air
2. Ultrasonic waves are often accompanied by broad-band noise and by sub-harmonics.

At levels below 105 dB SPL, however, there have been no observed adverse effects.

SONIC BOOMS

Present day knowledge regarding the acceptability of sonic booms by man is based on observations from both experimental field and laboratory studies and observations of community response to actual sonic boom exposures. Individual human response to sonic boom is very complex and involves not only the physical stimulus, but various characteristics of the environment as well as the experiences, attitudes and opinions of the population exposed.[G-22] One of the most comprehensive studies to date on sonic boom exposure of a large community over a relatively long period of time was the Oklahoma City study conducted in 1964.[G-23,G-24] Eight sonic booms per day at a median outdoor peak overpressure level of 57.46 pascals (or 1.2 psf)* were experienced by this community over a

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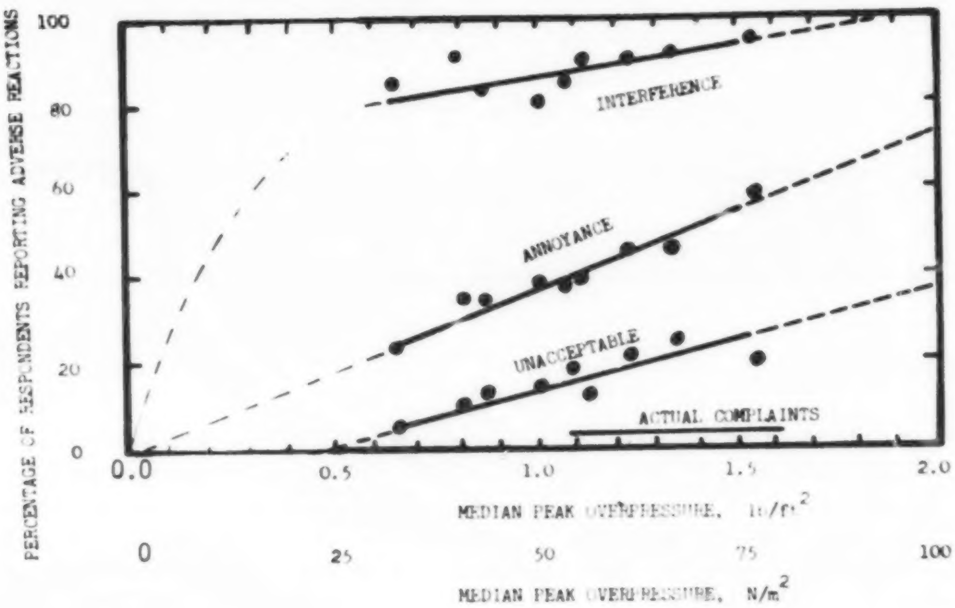
*1 psf = 47.88 pascals

6 month period. Some results of this study are summarized in Figure G-3. For eight sonic booms/day, there is clear evidence that the median peak overpressure must be well below 47.88 pascals (or 1 psf) if no annoyance is reported. When interviewed, part of the population considered eight sonic booms/day to be unacceptable. By extrapolation, the level at which eight sonic booms per day should be acceptable for the population is slightly less than 23.94 pascals (or 0.5 psf). But even at 23.94 pascals, approximately 20% of the population consider themselves annoyed by an exposure of eight sonic booms/day. Linear extrapolation of the annoyance data of Figure G-3 indicates that annoyance will disappear in the total population only when the 8 sonic booms per day are less than 4.79 pascals. A linear extrapolation is probably not entirely justified, however, as certainly for sonic booms much less than 4.79 to 9.58 pascals, a large percentage of the population is not even expected to sense the toom. The fact that the extrapolation must curve is best illustrated by the interference curve of Figure G-3. Unless the extrapolation is curved as shown, interference would be predicted for about 70% of the population even when the peak overpressure is zero, i.e., no boom at all.



NOTE: Data compiled from Oklahoma City Study. Dashed lines are extrapolations. All data for 8 sonic boom/day.[G-22]

Figure G-3. Percentage of Respondents Reporting Adverse Reactions to Sonic Booms

So far the discussion has been about eight sonic boom exposures per day on a daily recurring basis. The more difficult question is how to interpret the effect on public health and welfare of sonic booms that are more infrequent than eight times per day. Kryter[G-25] provides a relationship which indicates that a sonic boom of 90.97 pascals once a day would be equal to 110 PNdB or a CNR of 98 dB. It further suggests that the level (which is propottional to P^2) should be reduced by one half (3 dB) for each doubling of number of occurrences. From Appendix A, L_{dn} is approximately related to CNR by $L_{dn} = \text{CNR} - 35$ dB. Thus, a CNR of 98 equals an L_{dn} of 63 dB. If the sonic boom is made equivalent to an $L_{dn} = 55$ dB, so as to be consistent with the levels identified in the interference/annoyance section of this document, the level of one daytime sonic boom per day must be less than 35.91 pascals. For more than eight sonic booms/day, the level should be less than 12.45 pascals or $\frac{35.91}{\sqrt{N}}$ pascals. This result is slightly lower than the data from Figure G-3. However, extrapolating the annoyance line in the figure suggests that the 12.45 pascals level of 8 booms would annoy only 8% of the people and more would find it unacceptable. Therefore, the relationship proposed is: daytime peak over-pressure per day = $\frac{35.91}{\sqrt{N}}$ pascals where N = number of sonic booms/day. Thus, the peak over-pressure of a sonic boom that occurs during the day should be no more than 35.91 pascals if the population is not to be annoyed or the general health and welfare adversely affected.

The standard sound level meter, which is a time-averaging device, will not properly measure the peak sound pressure level of sonic booms.

REFERENCES FOR APPENDIX G

G-1. CHABA (Ward, *et. al.*, 1968), "Proposed Damage-Risk Criterion for Impulse Noise (Gunfire)," (U). Report of Working Group 57, NAS-NRC Committee on Hearing, Bioacoustics, and Biomechanics (CHABA), W. Dixon Ward, Chairman, Washington, D.C.: Office of Naval Research.

G-2. Guignard, J. C., "A Basis for Limiting Noise Exposure for Hearing Conservation," Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio and Environmental Protection Agency, Washington, D.C.: Joint EPA/USAF Study AMRL-TR-73-90 and EPA-550/9-73-001-A, 1973.

G-3. McRobert, H. and Ward, W. D., "Damage-Risk Criteria: The Trading Relation Between Intensity and the Number of Nonreverberant Impulses," *Journal of Acoustical Society of America,* 53: 1297-1300, 1973.

G-4. Poche, L. B., Stockwell, C. W. and Ades, H. W., "Cochlear Hair-Cell Damage in Guinea Pigs After Exposure to Impulse Noise," *Journal of Acoustical Society of America,* 46: 947-951, 1969.

G-5. Majeu-Chargois, D. A., Berlin, C. I. and Whitehouse, G. D., "Sonic Boom Effects on the Organ of Corti," *Laryngoscope,* 80, 620-630, 1970.

G-6. Coles, R. R. A., Garinther, G. R., Hodge, D. C. and Rice, C. G., "Hazardous Exposure to Impulse Noise," *Journal of Acoustical Society of America,* 43: 336-343, 1968.

G-7. Coles, R. R. A. and Rice, C. G., "Assessment of Risk of Hearing Loss Due to Impulse Noise," *Occupational Hearing Loss,* ed., Robinson, D. W., London & New York: Academic Press, 71-77, 1971.

G-8. Ward, W. D., Selters, W. and Glorig, A., "Exploratory Studies on Temporary Threshold Shift from Impulses," *Journal of Acoustical Society of America,* 33: 781-793, 1961.

G-9 Luz, G. A. and Hodge, D. C., "Recovery from Impulse-Noise Induced TTS in Monkeys and Men: A Descriptive Model," *Journal of Acoustical Society of America,* 49: 1770-1777, 1971.

G-10. Loeb, M. and Fletcher, J. L., "Impulse Duration and Temporary Threshold Shift," *Journal of Acoustical Society of America,* 44: 1524-1528, 1968.

G-11. Kryter, K. D., "Evaluation of Exposures to Impulse Noise," *Archives of Environmental Health,* 20:624-635, 1970.

G-12. Hodge, D. C. and McCommons, R. B., "Reliability of TTS from Impulse-Noise Exposure," *Journal of Acoustical Society of America,* 40: 839-846, 1966.

G-13. See Reference G-10.

G-14. Fletcher, J. L., "Effects of Non-Occupational Noise Exposure on a Young Adult Population," Report for Department of Health, Education and Welfare, NIOSH: HSM 099-71-52, Washington, D.C., HEW, 1972.

G-15. Cohen, A., Kylin, B. and La Benz, P. J. "Temporary Threshold Shifts in Hearing from Exposure to Combined Impact/Steady-State Noise Conditions," *Journal of Acoustical Society of America,* 40: 1371-1379, 1966.

G-16. Okada, A., Fukada, K. and Yamamura, K., "Growth and Recovery of Temporary Threshold Shift at 4 kHz Due to a Steady State Noise and Impulse Noises," *Int z angew Physiol,* 30: 105-111, 1972.

G-17. International Organization for Standardization (ISO), "Assessment of Occupational Noise Exposure for Hearing Conservation Purposes," ISO Recommendation ISO/R1999, Geneva: ISO, 1971.

G-18. Kryter, K. D. and Garinther, G., "Auditory Effects of Acoustic Impulses from Firearms," *Acta Otolarying (Stockh),* Supplement 211, 1965.

G-19. Coles, R. R. A., Rice, C. G. and Martin, A. M., "Noise-Induced Hearing Loss from Impulse Noise: Present Status," Paper to International Congress on Noise as a Public Health Problem, Dubrovnik, May 13-18, 1973.

G-20. Martin, A. M., In discussion, *1970 Teddington Conference on Occupational Hearing Loss,* ed., Robinson, D. W., London and New York: Academic Press, 89-90, 1971.

G-21. Martin, A. M. and Atherley, G. R. C., "A Method for the Assessment of Impact Noise with Respect to Injury to Hearing," *Annals of Occupational Hygiene,* 16:19-26, 1973.

G-22. von Gierke, H. E. and Nixon, C. W., "Human Responses to Sonic Boom in the Laboratory and the Community," *Journal of Acoustical Society of America,* 51:766-782.

G-23. "Noise as a Public Health Hazard," Proceedings of the National Conference on the American Speech and Hearing Association, June 13-14, 1968, D.C., Report 4, February 1969.

G-24. Borsky, P. N., "Community Reactions to Sonic Booms in the Oklahoma City Area," National Opinion Research Center, AMRL-TR-65-37, 1965.

G-25. Kryter, K. D., "Sonic Booms from Supersonic Transport," *Science*, 163: 359-367, January 24, 1969.

G-26. Public Health and Welfare Criteria for Noise, Environmental Protection Agency, 550/9-73-002, July 27, 1973.

☆U.S. GOVERNMENT PRINTING OFFICE: 1974 546-318/366 1-3